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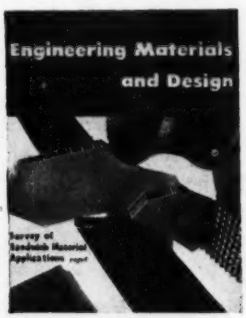

COVER—A selection of the growing range of structural forms possible with these materials. (Photo courtesy of Dufaylite Ltd.)

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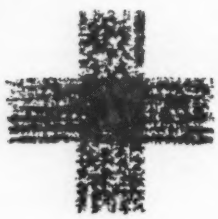

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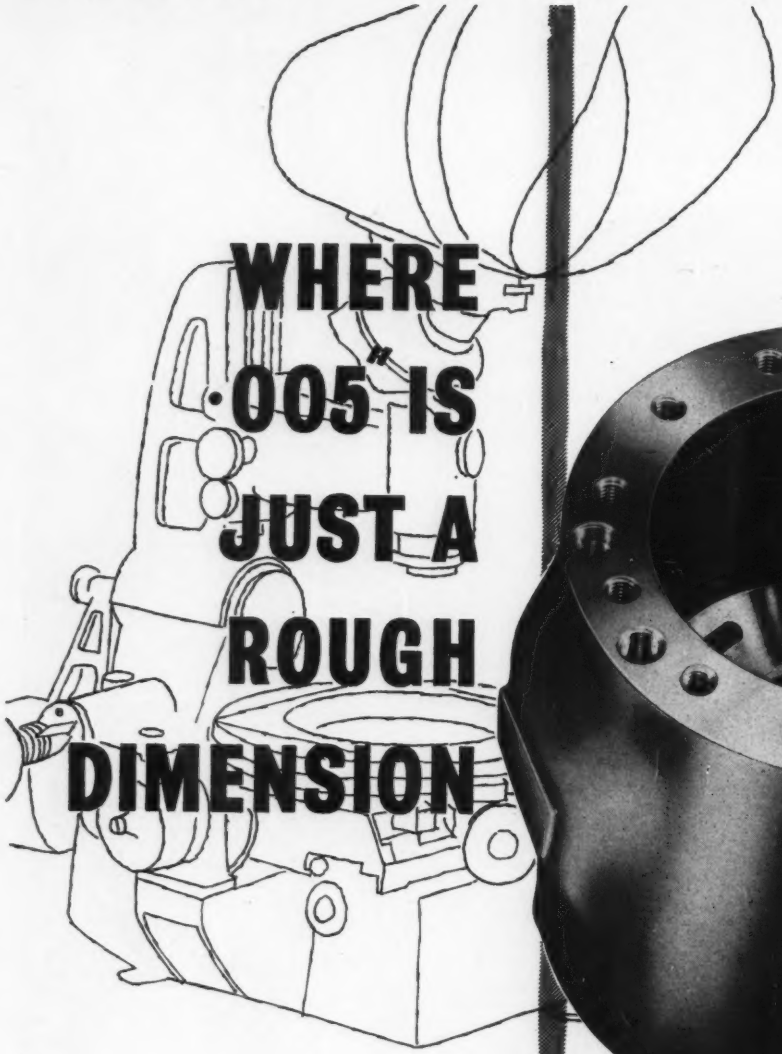

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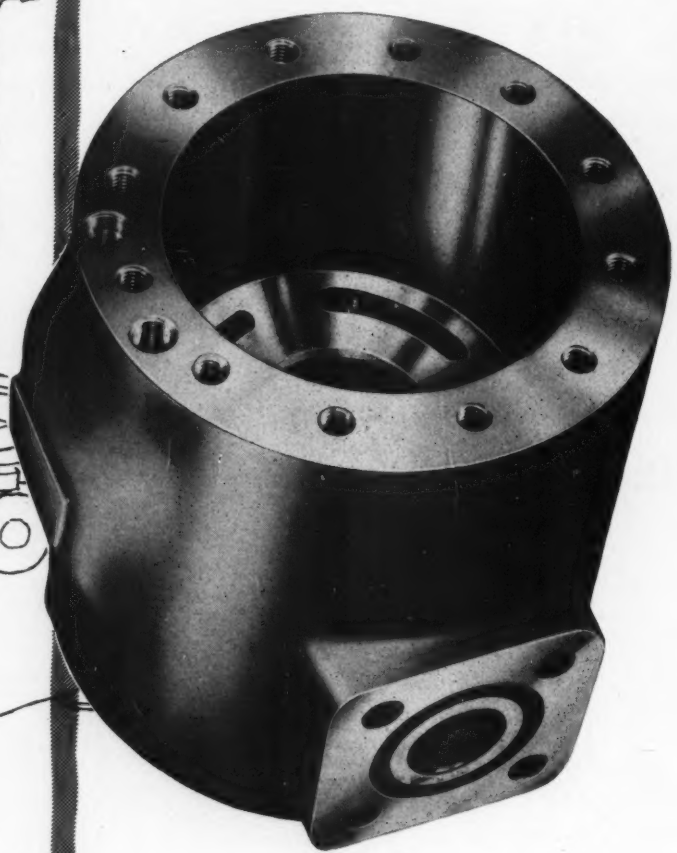

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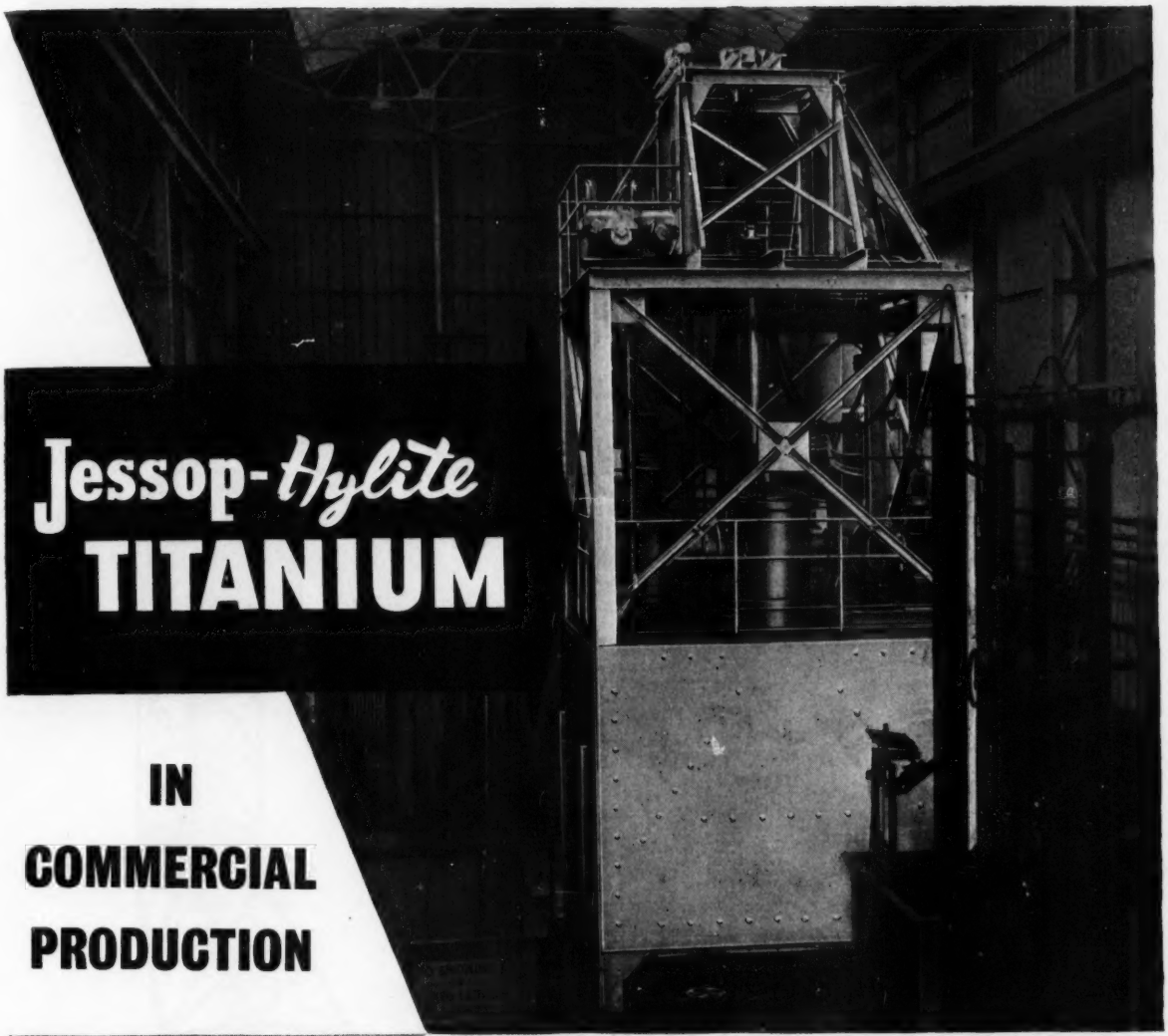

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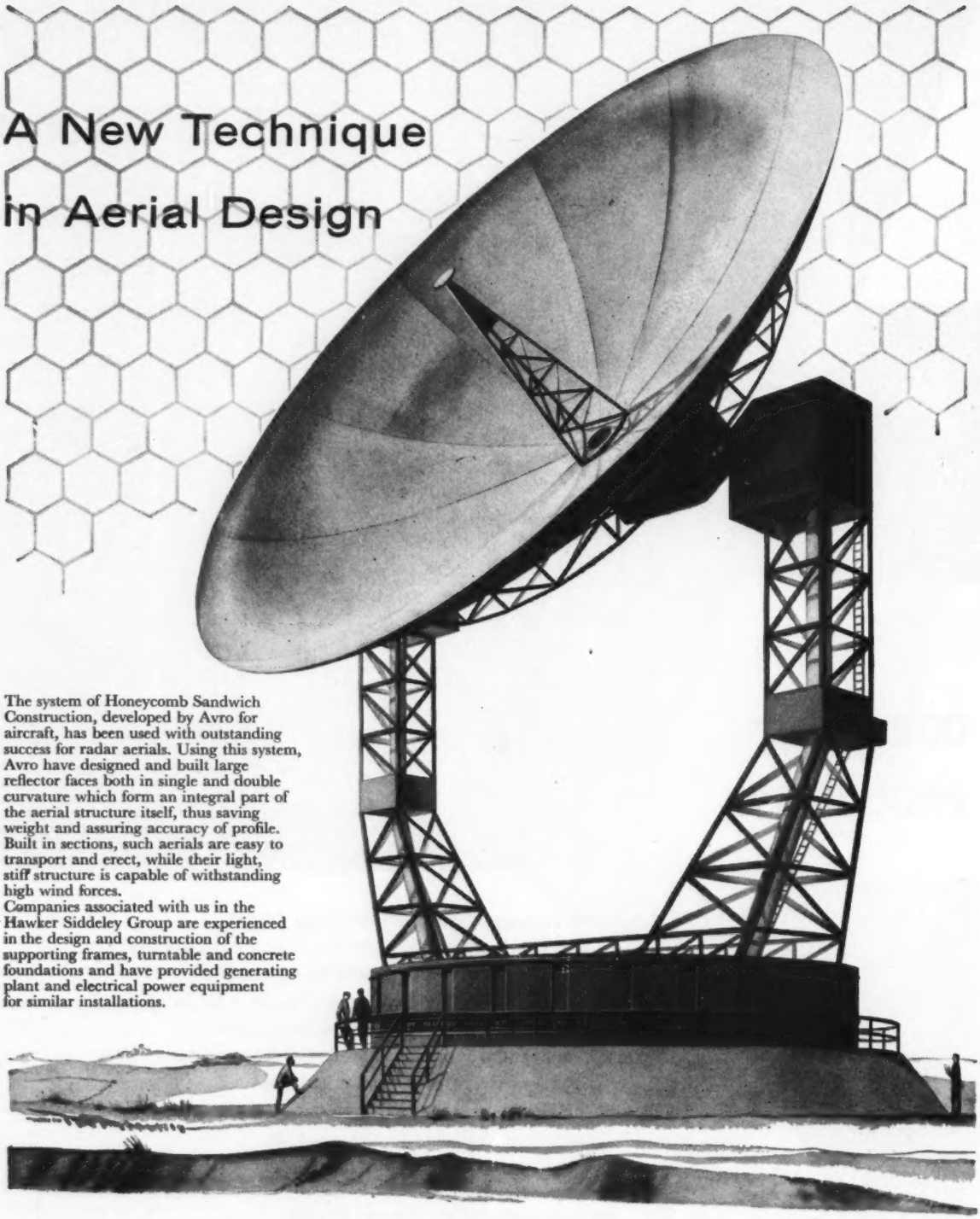

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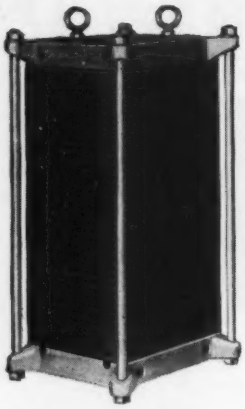

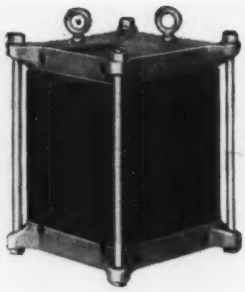

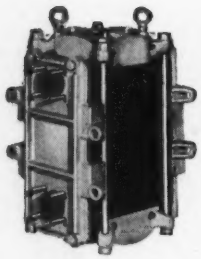

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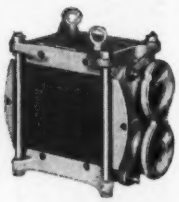
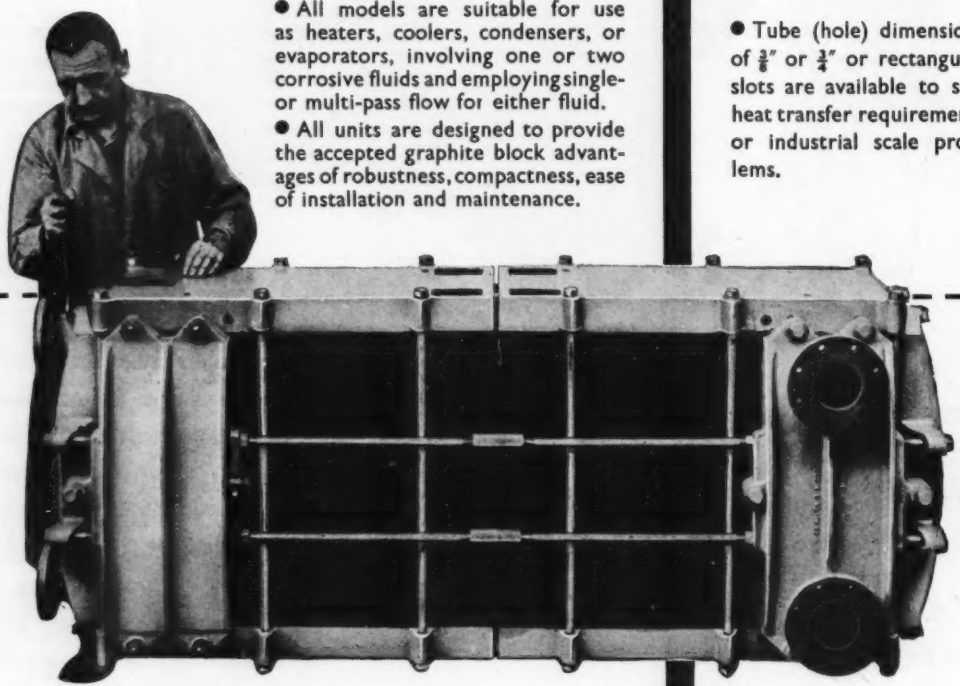


- Tube (hole) dimensions of $\frac{3}{8}$" or $\frac{3}{4}$" or rectangular slots are available to suit heat transfer requirements or industrial scale problems.



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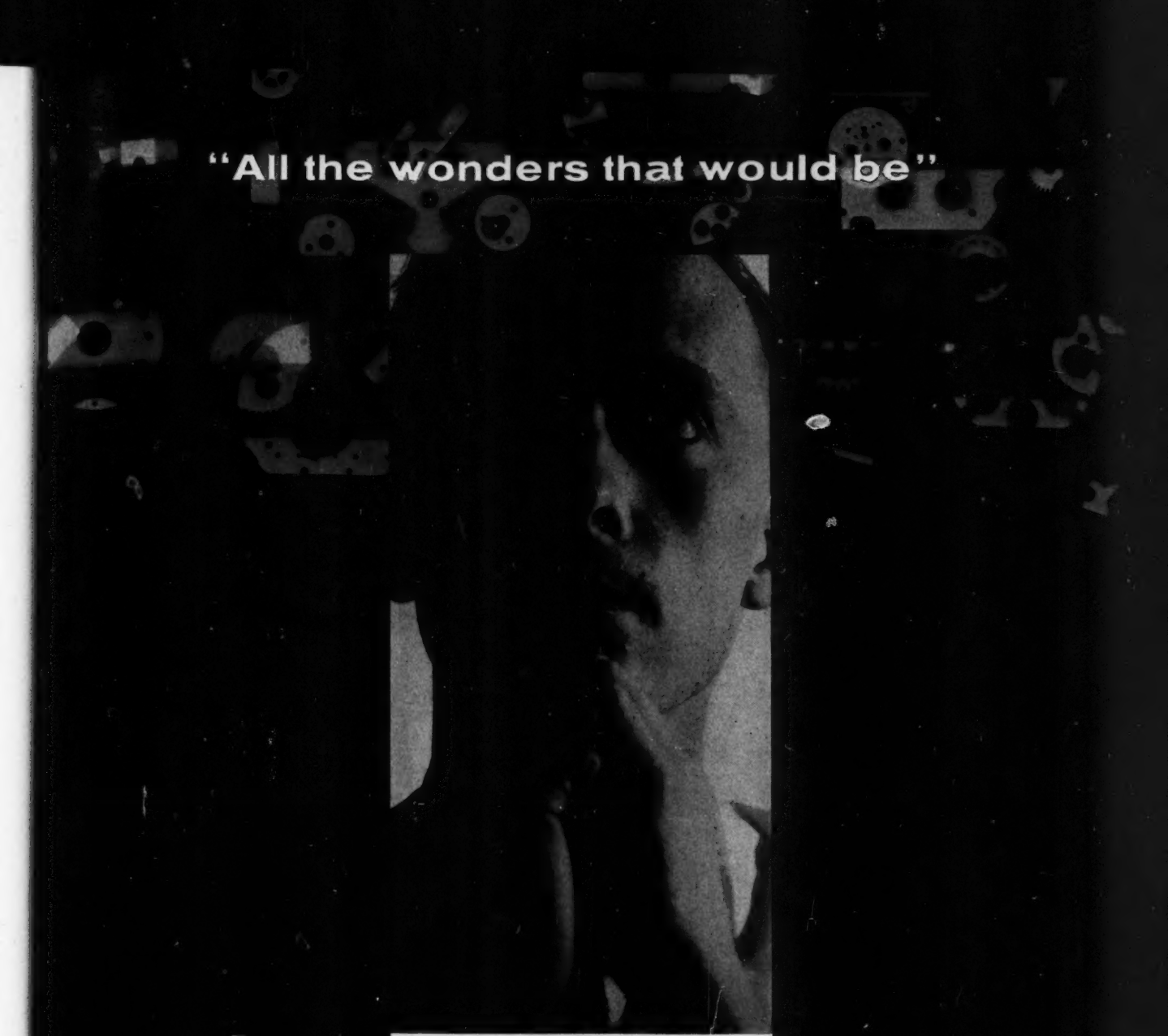

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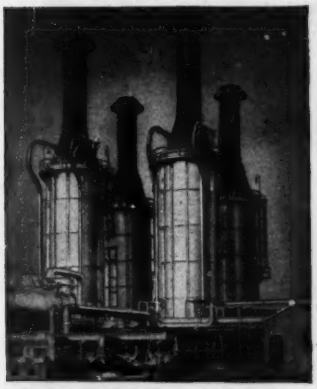

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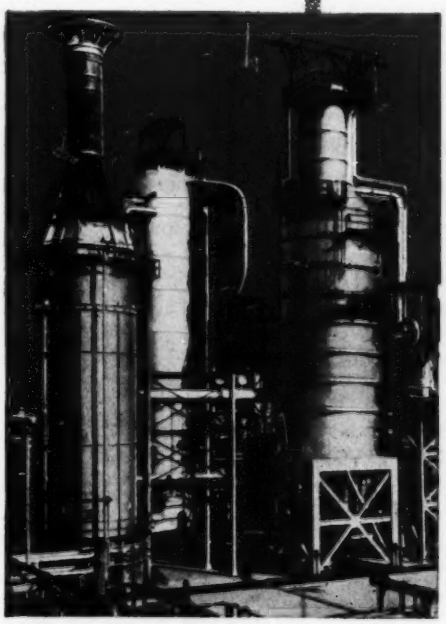

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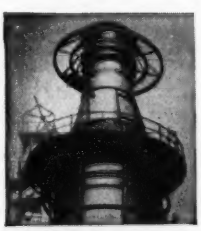

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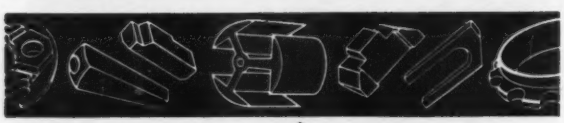

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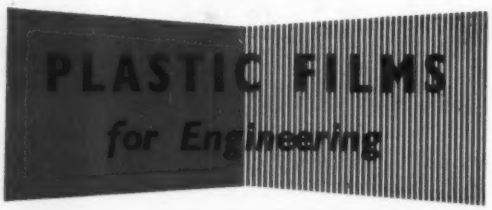

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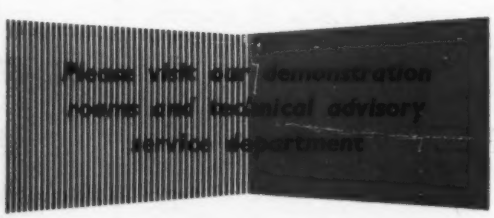

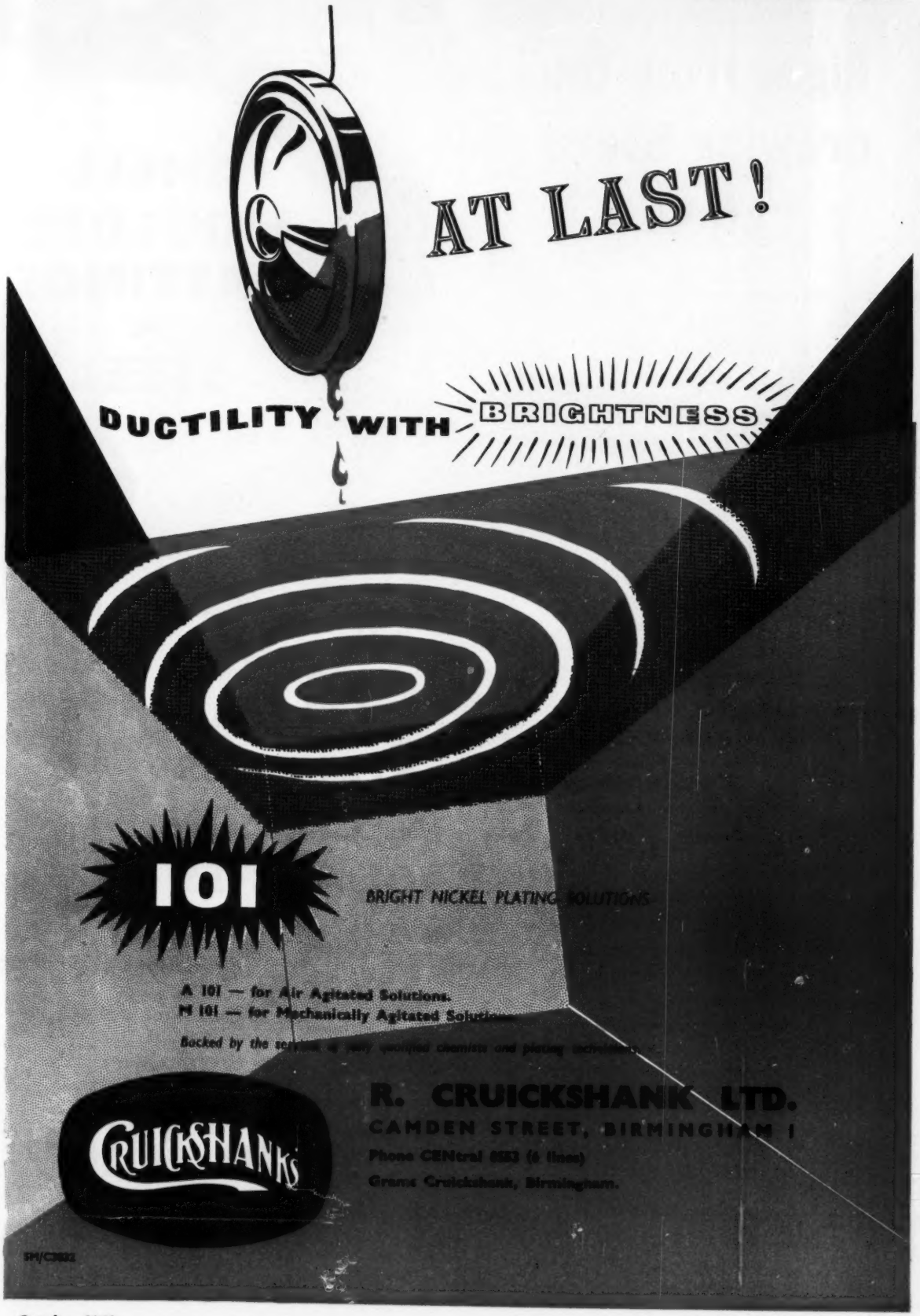
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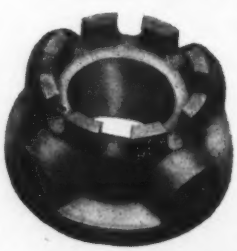

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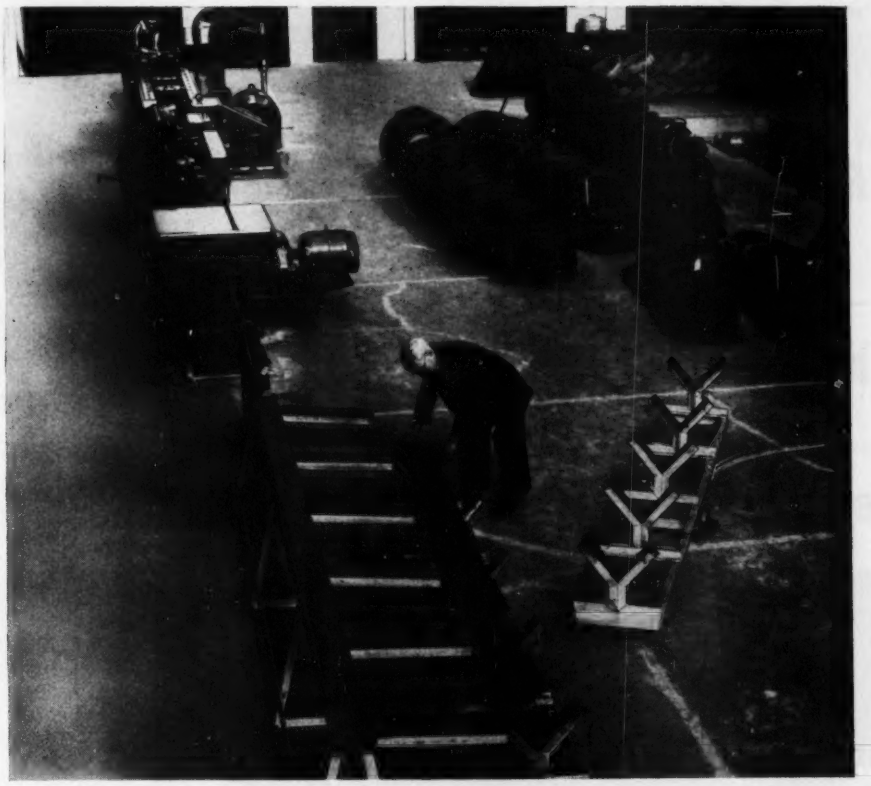

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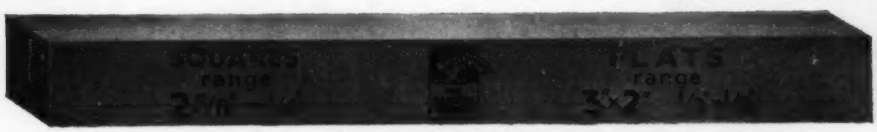

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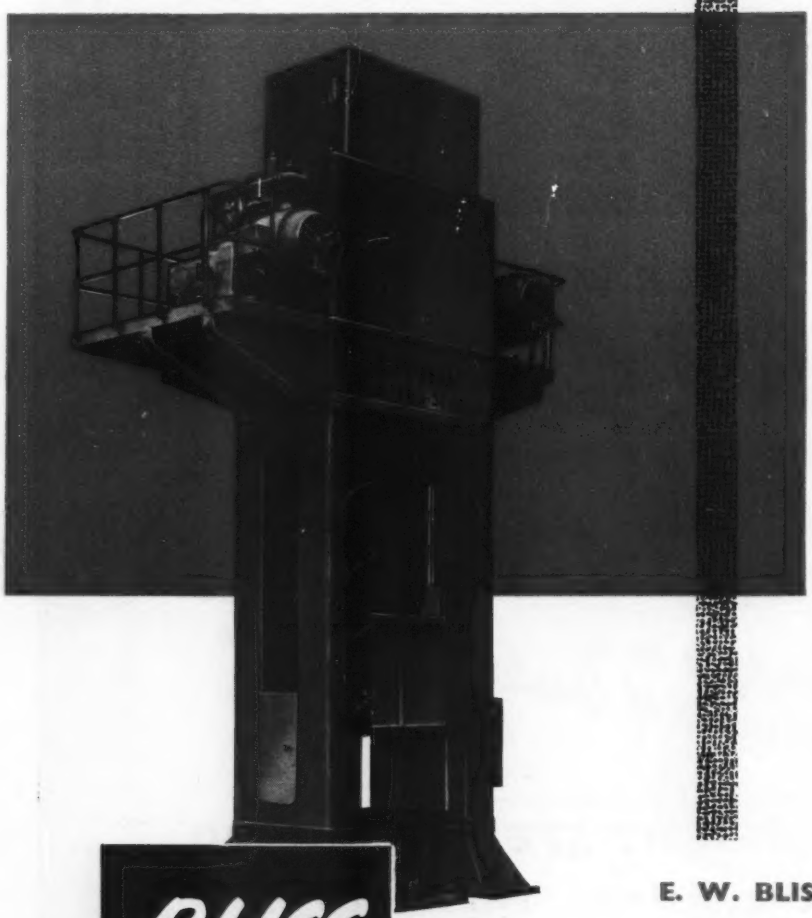

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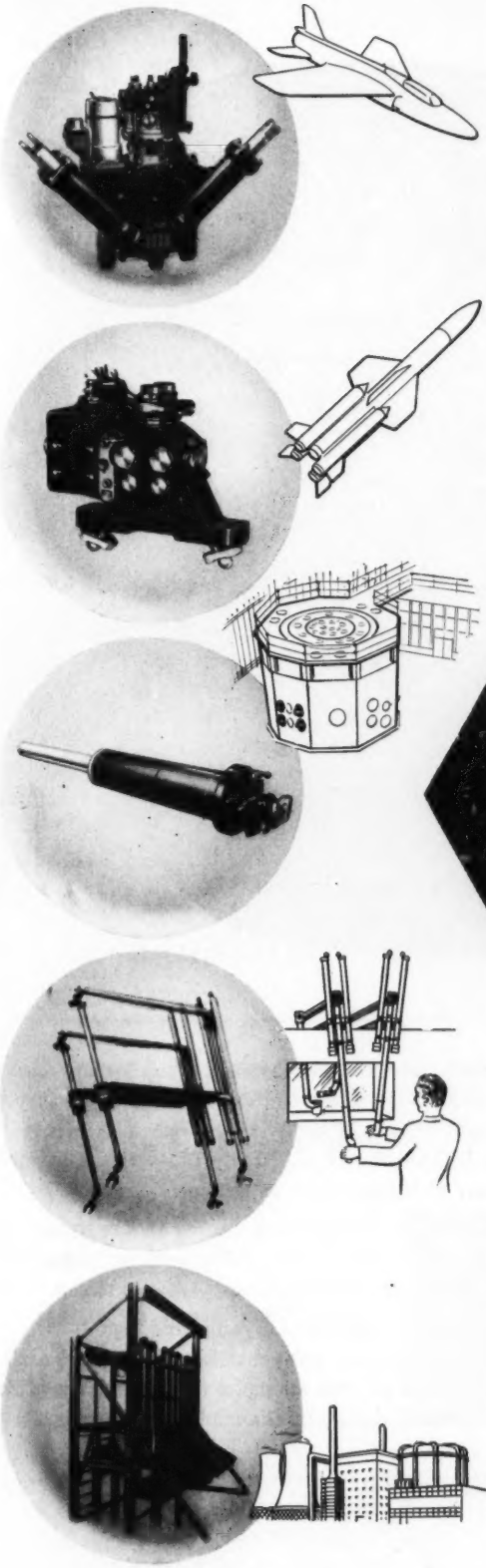

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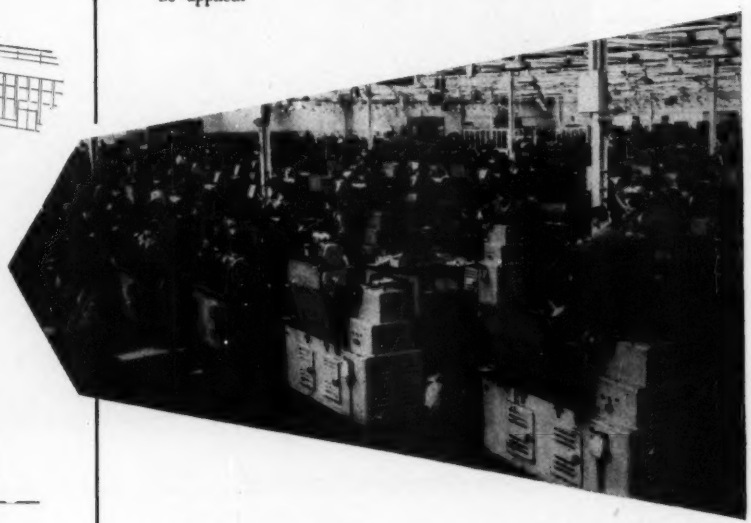

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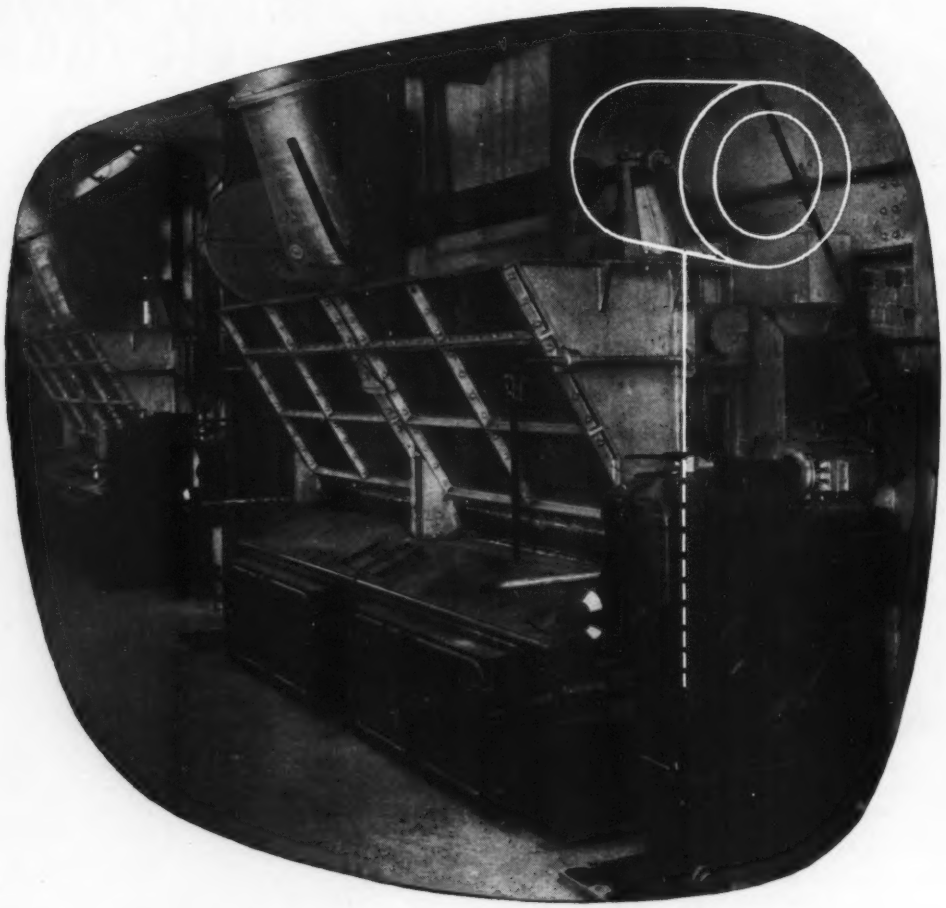

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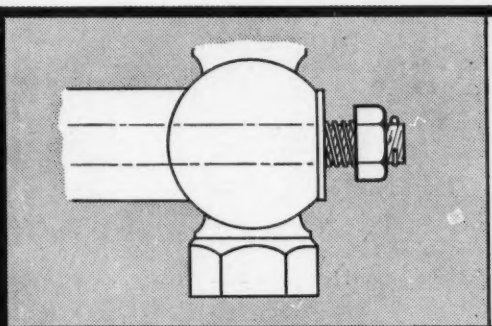
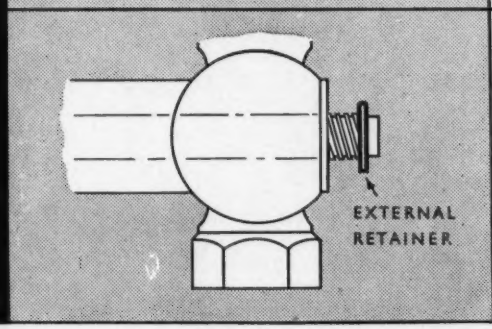


OLD WAY

To provide a shoulder for the tensioning spring on this filler cup entailed an extra long, threaded shaft, a nut, a hole drilled to take a cotter pin and an altogether tedious assembly.



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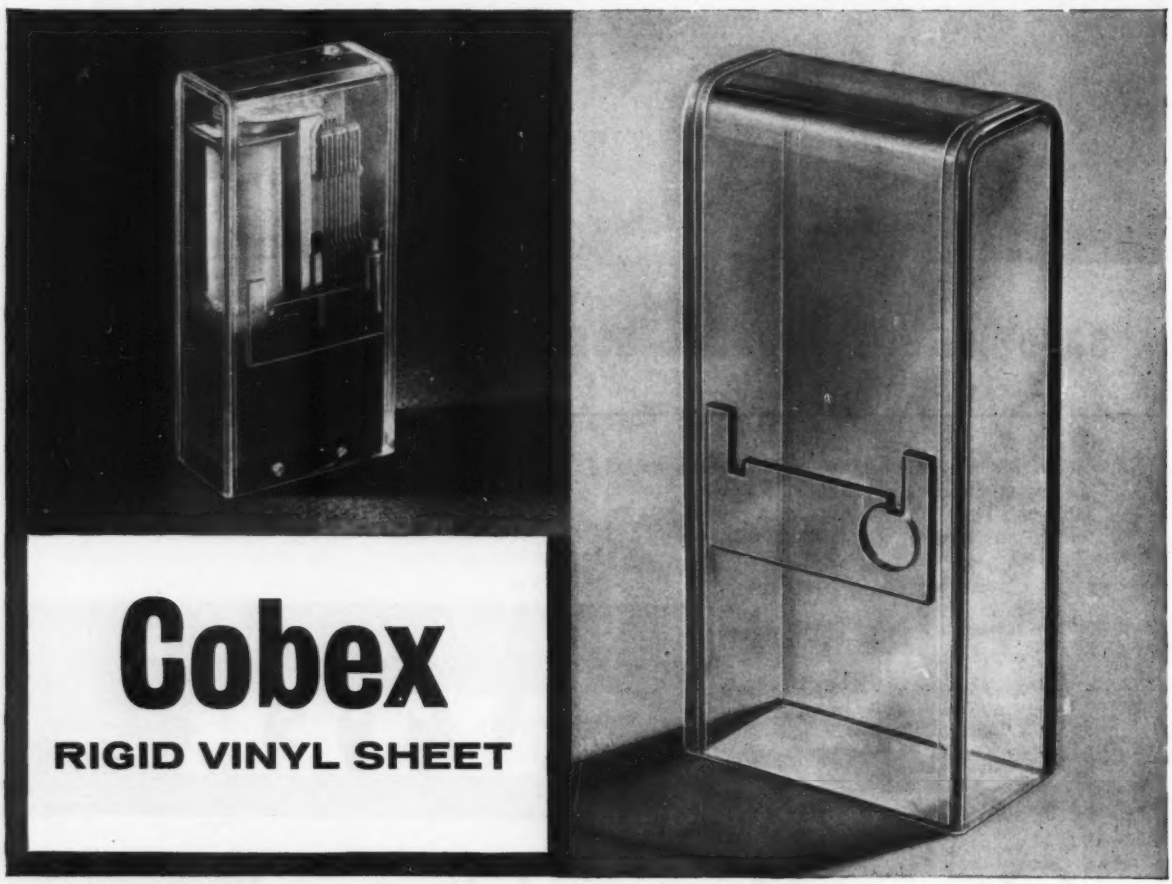

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MATERIALS IN THE NEWS

A Monthly Digest of Engineering Materials News from Home and Abroad

Beryllium—a Future or Not?

IMPERIAL CHEMICAL INDUSTRIES' announcement of the construction and operation of a wrought beryllium production plant on the basis of a contract from the U.K. Atomic Energy Authority follows earlier announcements by the Authority that this metal will be used in place of magnesium alloy as a canning agent for the fuel elements of the advanced design, high temperature, gas-cooled reactors which are currently being developed for the British nuclear power programme.

At the same time, it is of interest that beryllium is being talked about in the U.S. as the new "wonder metal" of the future, offering the opportunity of many potential industrial uses. Indeed, at one recent A.S.M.E. meeting it was stated that beryllium was the "true wonder metal of the future." Opinion in Britain is, however, less optimistic.

I.C.I.'s investment involves the expenditure of between one and a half and two and a half million pounds. The production of the plant— the location of which is being kept officially secret—is reported to be extremely flexible in that the likely demand for this metal even for atomic energy purposes is very uncertain. This must depend, not only on the success of beryllium as a canning agent, but also on the sale of U.K. nuclear power stations abroad.

Beryllium is, however, expected to find a number of applications in the manufacture of aircraft and guided missiles in the U.K. and also possibly in the chemical industry. To the aircraft industry its high temperature resistance and light weight are important assets.

Beryllium has a melting point of 1,280 deg. C., compared to 659 deg. C. for aluminium.

High Temperature Metals

LITTLE HAS BEEN published about recent U.K. developments in high temperature resistant metals. This work is of particular interest in the field of steel and other ferrous metals in that British research and development in this quarter is probably further advanced than work in other parts of Europe.

Developments from this research, which will be announced shortly, will include the production of new steel alloys—on a production basis—for the manufacture of steel sheet and steel piping. Brown Bayley Steels Ltd are, developing a series of high temperature steels. This company has specialised in the past in developing steels for special purposes. At the same time, both United Steel Companies and Stuarts & Lloyds Ltd. are developing more general purpose high temperature resistant alloys. Wm. Jessop & Sons Ltd. are also developing some new titanium-based alloys which should be available before the end of the year. Hadfields Ltd. also have a new boron steel under development.

Boron's Future

BORON is now well-known to be important as a potential guided weapon or rocket-to-the-moon fuel, and the U.S. has just fired its first production model solid-fuelled missile—the Nike Zeus. This is important because boron fuels, being solid, are easier to handle than liquids and also occupy less space. Recent research work in the U.S. has shown that the addition of boron hydride compounds to a basic ammonium perchlorate-rubber compound could yield a performance such that an inter-continental ballistic missile capable of travelling 5,000 miles would be only some five feet in diameter and fifty feet in height. This is a reduction in height of about thirty feet where liquid fuels are involved.

While diborane and boron come high on the list of potential rocket fuels, they will not be used as a straightforward chemical compound, but will be combined with other materials as, for example, magnesium, aluminium and lithium.

It has been estimated, according to recent calculations carried out in the U.S., that the use of boron fuels for guided missile propulsion would, in the case of most missiles, give an increase in the amount of propellant loading on fuel space; indeed, loadings of between 90 and 95 per cent are being achieved already with experimental missiles. Boron-based fuels will not, however, save weight, although they will be slightly cheaper than conventional rocket fuels to produce. Boron-based fuels also have potential civil applications and both German and French companies are carrying out research programmes on the use of these materials for boosting jet engine performance and overcoming "flame out."

The U.S. Air Force has recently awarded a contract to the U.S. Borax Research Corporation—a U.S. subsidiary of the U.K. Borax (Holdings) Ltd.—for the investigation of new solid rocket propellants based on the combination of boron compounds with inorganic polymers.

Aluminium for Canning

ONE OF THE potential uses for aluminium that has previously been neglected because of the problems involved is the use of this metal for the production of cans for containing mineral waters.

One of the major problems here has been the fact that aluminium oxidises far too readily and, as a result, taints the liquid enclosed in the containers.

The French company of Boxal has now developed a process which, it is claimed, overcomes this problem and should enable aluminium to be used for this purpose.

An obvious advantage of the use of aluminium for such canning purposes lies in the fact that it could lead to considerable savings in weight over the glass bottles currently used. Estimates place the weight which could be saved at about six hundred tons per million containers handled.

Cermets—Cost and Use

WHAT IS the position about cermets—ceramic-metal compounds? The future seems to lie between their use in atomic energy as a high temperature resistant fuel element for nuclear power plants —based on uranium oxide and graphite—or, alternatively, their failure to find an economic industrial use unless production processes can be improved so that they can be used for the manufacture of ball bearings and other similar small engineering components. The use of cermets for the manufacture of high temperature thermocouples has, in the U.K. at least, proved on investigation with experimental trials to be uneconomic. Detailed experiments carried out over several years concerning the manufacture of turbine blades for jet engines have also shown, it seems, that the use of cermets for this purpose is not possible, because they cannot meet the particular technical conditions—chiefly ease of fabrication and mechanical performance—which are required. At the same time, cermets seem likely to form the basic element of the nuclear reactor furnace of the atomic power stations of the future, such as that now being constructed at the new U.K. Atomic Energy Authority reactor testing research station at Winfrith Heath, Dorset.

Dumping Aluminium

RECENT COMPLAINTS about the dumping of aluminium have been brought to the notice of the Board of Trade by the Aluminium Company of Canada.

Figures of Soviet aluminium production are unavailable, but they are believed to be considerable. This is supported by the fact that Russian industrial usage of this metal has grown considerably during the last five years. The question which is being asked is whether Russia is exporting aluminium as a measure of economic warfare, or whether she is merely exporting it as a non-political surplus. On the whole in the past Russia has tended not to export basic materials even where an excess production is known to exist—as is the case with oil—except for political reasons.

At the same time, the Russian production of aluminium is believed to be far in excess of the quantities of this metal which could be used in its industry. This is especially the case from deposits which occur in the Urals and Asia, and it may well be that Soviet economists have decided now that trading at a price which will meet their production costs (low compared with those of most Western countries) is profitable both economically and politically.

Soviet Plastics

RUSSIAN PRODUCTION of plastics, which is believed to be currently running at between 100,000 and 150,000 tons a year, is to be stepped up considerably, according to the latest plans to be announced.

Russia is not only in the market for plants for the production of polyethylene, but also for the production of polyurethane, polypropylene and a series of man-made fibres of potential industrial importance.

Russian production of plastics is extremely variable. At present Russia is producing about 1,000,000 lb. a year of fluorocarbons and between 8,000,000 and 10,000,000 lb. of polyurethanes. Her production of both polyethylene—using a high pressure process—and of polyester resins is believed, however, to be considerable. Considerable quantities of silicones are also being produced.

The main weakness of Russian plastics production at the moment would seem to be confined mainly to her production of man-made fibres and advanced types of synthetic rubbers. On the other hand, a considerable amount of research and development work is being undertaken in these fields and recent research on "natural" type man-made rubber—full details of which are not yet available in the U.K.—carried out at the Institute of Macromolecular Chemistry would seem to indicate that in the latter field at least Russian progress does not lag far behind that of the West.

Coated Steel

FOUR COMPANIES in the U.K. have now acquired the rights to buy the British Iron and Steel Research Association's Plasteel process and are laying down production lines.

John Summers & Sons Ltd., on the other hand, who also have developed a plastic coated steel, are, according to the latest reports, very heavily committed on production orders and are not seemingly at present selling the rights to their process.

The purchasers of the BISRA process include Richard Thomas and Baldwins, Morgan Electrofinishes of Port Talbot, Wilmot Taylor, and Guest, Keen & Nettlefold. A number of Commonwealth and foreign companies are also interested in the BISRA coated steel. They include the Dominion Fabric & Steel Co. of Hamilton, Canada, who have already come to an agreement for its production. Other foreign companies from Australia, Italy, Holland and Germany are still negotiating.

Plastics—After Ziegler

THE SHELL CHEMICAL COMPANY are now preparing to go ahead at Grangemouth with the Phillips polyethylene production process.

Two and a half years ago, Shell Chemical bought the exclusive rights of the Ziegler polyethylene production process in the U.K., but they are still investigating the potentialities of this technique.

At the same time, the use of Ziegler catalysts has seemingly been abandoned for the production of polypropene, both in Europe and in the U.S. The unit using the Phillips process will be constructed in collaboration with British Petroleum Co. Imperial Chemical Industries, meanwhile, are continuing with further developments of their high-pressure polyethylene production process and are considering expanding production capacity. The Russian delegation that recently visited the U.K. for the purpose of buying chemical plants showed itself especially interested in the purchase of an I.C.I. high-pressure polyethylene plant, and the Russian government has recently made the first steps towards the negotiation for the purchase of a production plant of this type.

Bridges on Rubber

A RUGGED new application is developing for that highly versatile material—rubber. Since it was put to use as a bridge mounting for the first time in this country on Lincoln's Pelham Bridge this summer, it has been used also on the footbridge of the ornamental lake in St. James's Park in London and, currently, to a section of the Chiswick Flyover. Here apparently is the start of a new trend in bridge building. At present, there are nearly a dozen small bridges forming part of the new Gloucester by-pass being mounted on rubber, and one authority has forecast that within the next two years there will be about 200 bridges mounted on rubber in Britain. British Railways are understood to be taking a close interest in the development.

Movement of bearings is of course necessary on most bridges to allow for expansion and contraction, but many civil engineers regard conventional metal bearings as far from ideal. This has been partly because of lack of maintenance, but a very frequent trouble has been the result of fretting rather than substantial movement, and it is believed that rubber mountings are an answer to this.

Engineers of the Andre Rubber Co., working in consultation with W. S. Atkins & Partners, produced for the Pelham Bridge bearings measuring 24 in. × 16 in. × 7 in. deep with intermediate bonded steel plates; each of these (fitted directly between the piers and the steel girders) is capable of carrying a vertical load of 100 tons at a rate of 1,200 tons per inch.

Alloy for Missile Noses

ONE OF the biggest problems in the development of intercontinental ballistic missiles is to prevent them burning up when they re-enter the dense air near the earth while travelling at high Mach numbers.

The U.S. National Advisory Committee for Aeronautics has been studying nose shapes that will dissipate this heat instead of being consumed by it. For these test purposes, an alloy is needed that will maintain structural stability at very high temperatures, and a material which research workers are now using for this is Inconel, a neat-resisting nickel-chromium-iron alloy. This alloy is also valuable for this purpose because it can be readily spun into a great variety of experimental nose shapes which are needed.

The cones are heat-treated to obtain the minimum grain size and then hand-polished to a finish much smoother than glass to eliminate microscopic roughness which might cause frictional heating.

Electronic Refrigeration

THE PRINCIPLE of electronic refrigeration has been known for more than a century. But the problem has been to apply the theory—of passing electricity through junctions of two dissimilar materials to create heating or cooling—on a commercial basis.

An announcement by the Westinghouse Electric International Co. suggests the advent of this technique is very much nearer. The company has produced a semi-conductor device that both cools or heats a baby's bottle automatically, and a food trolley with both refrigerator and oven compartments. Other items envisaged though not yet made are refrigerated mixing bowls, kitchen cabinet drawers, as well as air-conditioning units, cooling coaster mats, photo-developing trays and electric thermos bottles. In short, the technique may lead to a breakaway from the refrigerator as a single unit in favour of components of various types of cold storage drawers, cabinets and closets around the kitchen and other rooms in the home so that they would be located where they are most needed.

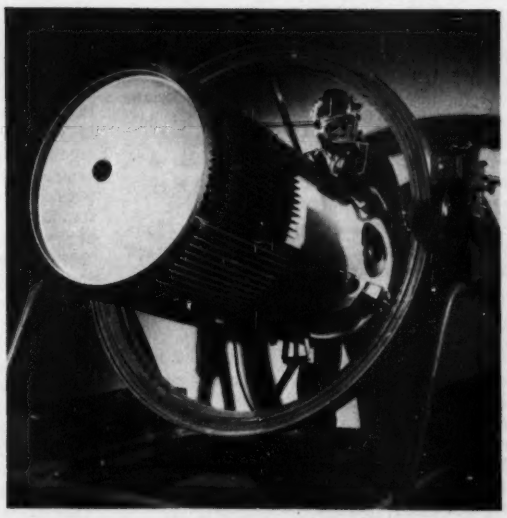
PICTURE NEWS
IN THE WORLD OF MATERIALS

LIGHT ALLOY IN SELF-RIGHTING LIFEBOAT

This 37ft. self-righting lifeboat built by Wm. Osborne Ltd. makes extensive use of light alloy in the double-bottom of the craft forming the ballast tanks, as well as in the superstructure and some bulkheads. Hull itself is of double-skin mahogany.

TITANIUM DUCT ASSEMBLY

Seen at the Farnborough Air Show this year was this duct assembly in I.C.I. titanium 130, part of the blown flaps (shown lowered) on the Vickers Supermarine Scimitar naval aircraft shown in this picture about to deck land.

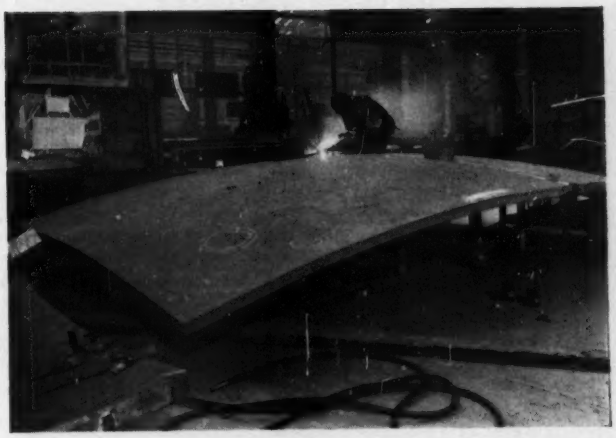


CONVERTERS READY FOR FINISHING

Absolute cleanliness before painting is an important factor in the manufacture of steel envelope mercury-arc converters for reversing drives in the steel and mining industries. Wire brushing is shown here being carried out at the Stafford works of English Electric Co.

POLYESTER-GLASS FIBRE SPORTS CAR

Body of the new Peerless sports car is made up of 57 individual Cellobond polyester-glass fibre mouldings, including those for foot wells, most bulkheads and seat frames. Chassis is built up from rectangular steel tubes, fabricated from sheet, and with the seams flash-welded.



PLATES FOR HINKLEY POINT

A 3in. thick steel plate for the 67 ft. diameter reactor pressure vessel at Hinkley Point nuclear power station being tack-welded prior to fabrication at the Renfrew works of Babcock & Wilcox Ltd.

"Atoms for Peace" — Materials at Geneva

ONE OF the most striking features of the Atomic Energy Exhibitions at Geneva which were held in conjunction with the "Atoms for Peace" international conference was the important place occupied by special materials and engineering equipment.

There were two exhibitions, one—the scientific exhibition—being held in a specially constructed hall adjoining the Palais des Nations, and the other being held in the Palais des Expositions in the city itself. Together they contained the largest collection of atomic energy equipment and materials exhibits ever assembled in the world.

The dependence of the future of atomic energy development both for power production and for other industrial purposes on the development of new engineering materials such as zirconium, beryllium, and niobium and on the development of new forms of already well-known types of materials such as concrete, plastics, graphite and ceramics, was strikingly demonstrated.

One of the outstanding exhibits in the British section, for example, was a new type of ceramic uranium fuel element which is being tested for operation in the P.L.U.T.O. reactor at the Atomic Energy Research Establishment, Harwell, at temperatures of the order of 800 deg. C. This was exhibited by the de Havilland Nuclear Power group.

Both Imperial Chemical Industries and Tube Investments Ltd. showed novel developments in the field of zirconium, titanium, vanadium, niobium, and other alloys, which can be used for either cladding uranium fuel elements of reactor furnaces, or for structural purposes in the construction of reactors. Thus, I.C.I. exhibited a titanium ingot weighing nearly two tons, which is the largest ingot of this metal yet made in Europe. The same company also showed examples of the zirconium fuel element support brackets which are to be used in the Berkeley nuclear power station, together with a series of new zirconium alloys for use in nuclear engineering and examples of the Integron finned tubing for use in heat exchangers. Nearly 400 miles of this material—which has been specially developed for use in nuclear engineering—made in steel have already been produced for use in the Berkeley and Bradwell power stations. The material can, however, be made in several metals. T.I. likewise showed a variety of new types of heat exchanger tubes made in mild steel, chromium molybdenum alloy steel and other materials, and some impressive fuel element cans made from beryllium.

Heat exchanger units and reactor components made from zirconium were also shown by W. C. Heraeus of Germany and by several American companies, including the Carborundum Co.

In the field of more conventional materials that have been adapted and intensively developed in new forms for atomic energy purposes, the U.K. General Electric Company's graphite, which is completely impermeable to gases, and which is designed for use as a fuel canning material for reactor furnaces operating at extremely high temperatures is of especial interest. Details of its performance were demonstrated on the stand, where a graphite tube was charged with carbon dioxide gas (which is used for removing the heat in U.K. nuclear reactor furnaces) at a pressure of ten atmospheres and a temperature of more than 500 deg. C., while the outside of the tube is maintained in a vacuum. Even under these stringent conditions there was no leakage of gas from inside the tube to the outside.

Nuclear Graphite Limited (which is a jointly-owned subsidiary of the Morgan Crucible Co. and the A. E. I. John Thomson Nuclear Energy Co.) also demonstrated a number of new developments in their field of graphite products, including the techniques which they have developed for use in machining this material. Union Carbide International Company also had an impressive demonstration of their work in the field of graphite technology together with some very striking canning and reactor engineering fabrications made from tantalum, vanadium, and niobium.

Plastics were well represented in both exhibitions both in the form of special boron and cadmium filled compounds—for use as lightweight radiation absorbing materials for shielding purposes in reactor construction and the handling of radioisotopes—and in the form of irradiated plastics having special physical and mechanical properties of benefit to non-atomic industrial users. Even oils were represented; for example, by the Shell Petroleum Co. Special oils have had to be developed for use in the lubrication of both nuclear reactor parts and the equipment used in plants concerned in the manufacture and processing of radioactive materials. Shell radiation-resistant lubricating oils and greases, which were developed as a result of research at the Thornton Research centre in the U.K. and the U.S.A., are now being supplied on commercial contract to nuclear research establishments not only in the U.S. and the U.K. but also in France, Denmark, Norway and Sweden.

An actual working demonstration of the importance of these newly developed materials and methods of fabrication was shown in the two operating nuclear research reactors exhibited by the U.S. Atomic Energy Commission and the operating experimental apparatus for research into controlled thermonuclear power demonstrated both by the U.S. A.E.C. and by the United Kingdom Atomic Energy Authority at the Palais des Nations scientific exhibition.

Farnborough Air Show

VERTICAL TAKE-OFF and guided missiles provided the emphasis this year at the aircraft industry's shop-window—the Society of British Aircraft Constructor's exhibition at Farnborough.

Specialised plastics were much in prominence, and the plastics divisions of some of the major companies, such as de Havilland Aircraft Co. and Bristol Aircraft Co., had some varied and interesting products on display. Glass fibre reinforced plastics were in evidence in the DH Chipmonk, which employs a hopper for agricultural work or a container for normal freight (both in this material), and in the Microcel exhibit which included for the first time their range of rocket launchers in this material.

In the components field the trend was towards precision and miniaturisation, with examples ranging from the Sperry potentiometer to miniature motors for instrumentation. Non-destructive testing equipment was well to the forefront with examples of the Sperry Introview flaw detector, with particular application to non-ferrous tubes and sections; this instrument works on the Eddy current principle and is being further developed for a much wider range of applications.

A completely new range of products was featured by Aero Plastics Ltd., a subsidiary of the Fairey Aviation Co. With the introduction of their pre-impregnated reinforced materials, they are offering to industry products which previously have been available only in the U.S. Pre-impregnation means that reinforced plastics material can now be used in the same way as a standard laminated material, a development which takes most of the responsibility for quality control out of the hands of the operators on the shop floor. The materials can be cured by conventional methods by pressures of 10 to 200 p.s.i. and at temperatures of 93-138 deg. C.

Shown for the first time by the Solartron Electronic Group Ltd. was the Solartron Minispace—the "electronic slide rule." This is a small computer designed to meet the needs of engineers and physicists and is a precision desk-side or laboratory tool at a very reasonable price. Henry Wiggin & Co.'s stand featured the introduction of Nimonic 105, a further heat- and creep-resisting alloy in the Nimonic series. It has a greater resistance to creep at a very high operating temperature than Nimonic 100, the minimum life to rupture at 15,680 p.s.i. 940 deg. C. being 50 hours.

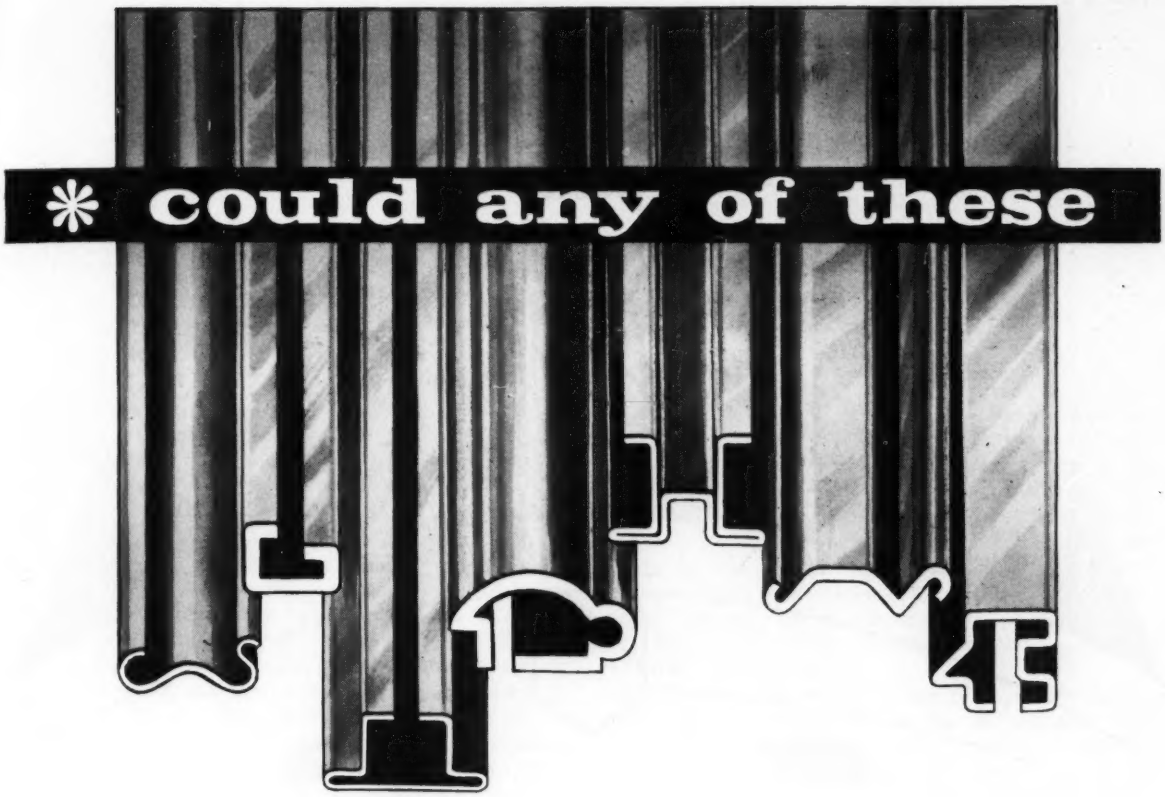
Plastics laminates for industry by the Coin Insulation Co. included products such as spherical bearings for nose-wheel units and for gears, and a topping-up nozzle.

Alloys' Better Creep Resistance

A STUDY made by the U.S. National Bureau of Standards indicates that the creep resistance of nickel-copper alloys is superior to that of the parent metals.

Data produced from tests made at 370 deg. C. and 480 deg. C. show that a 30-per cent copper alloy was far more creep resistant than a 70-per cent. copper alloy, regardless of the time under stress. The strengthening effects of alloying were far more pronounced as the time at stress was increased and the temperature decreased. These observations were confirmed when the two alloys were tested at 650 deg. C.

The experimental results obtained in the study showed a lack of strict conformance to any of the known comprehensive theories on high-temperature deformation. This was attributed both to the initial structure of the specimens and to subsequent structural changes during creep.



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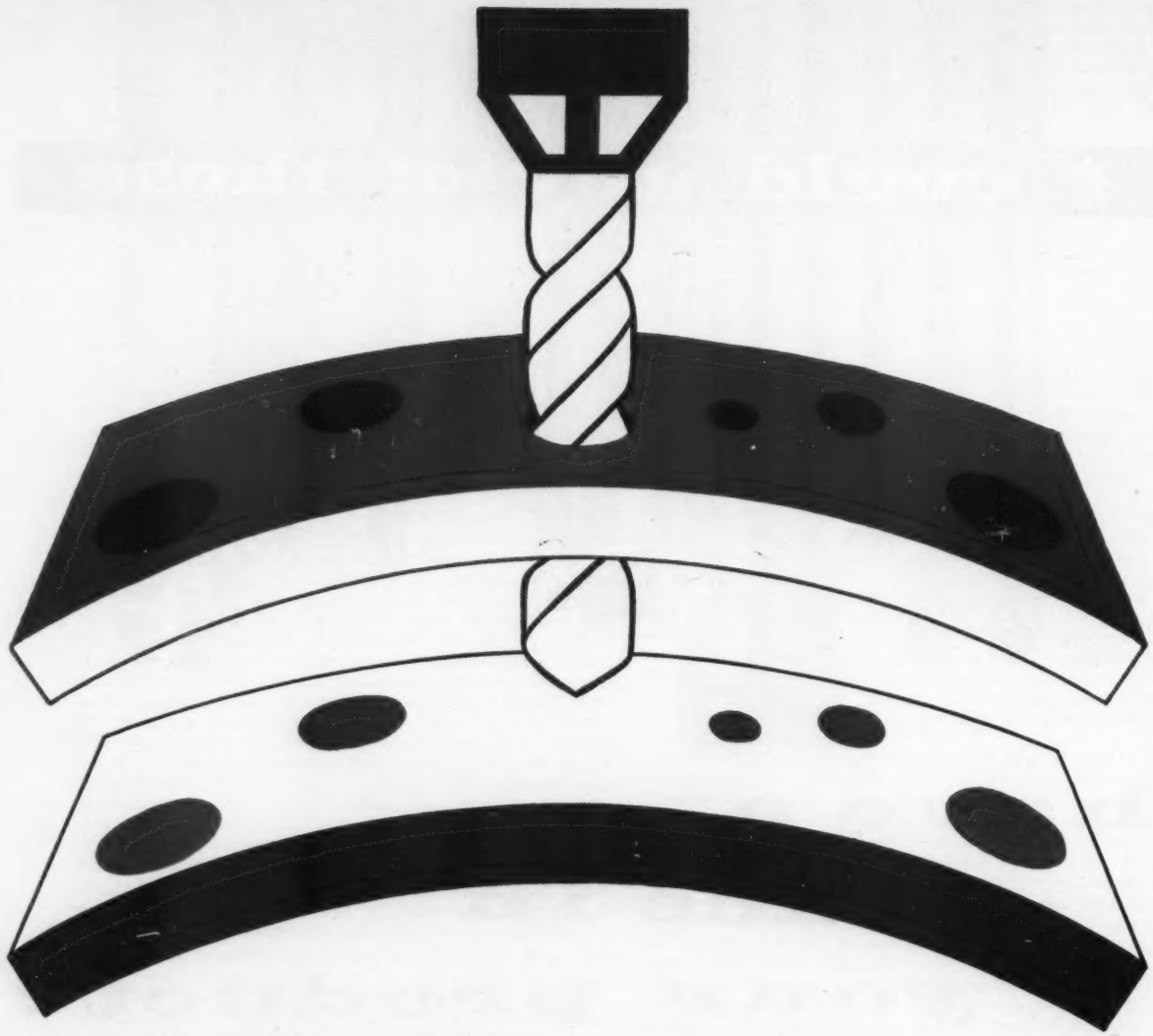

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Engineering Materials and Design

THE CHALLENGE OF MATERIALS

THE most remarkable feature of the age in which we live is the tremendous and still accelerating pace of advancement in every branch of technology. This has created many new demands, not the least of which is the need for developing new and better materials. On the one hand, there are new technologies, such as nuclear engineering and guided missiles, which involve conditions of temperature, speed and pressure under which traditional materials would quickly break down. On the other hand, there are vast technological changes in older industries, brought about by more stringent requirements on the part of the buyer, keener competition and the necessity for large-scale output, all of which call for intensive mechanisation and constant renewal and redesign of plant and machinery. Here, too, progress demands the adoption of new materials.

To meet these needs, there has been a fantastic development since the war of new metals, plastics and ceramics. It is often difficult to decide which came first, the new material or the demand for it. Whatever may be the order of events, the engineering designer is now confronted with a bewildering and rapidly increasing range of materials which he ignores at his peril.

Progress has been rapid and far-reaching in every class of material. In metals, a vast group of new alloys has been produced, each with special advantages; one may combine lightness with high strength, another may be suited to high-temperature working, another may possess complete resistance to certain corrosive conditions. Simultaneously, in the last five years, there has been unceasing activity in the development for industrial purposes of metals and alloys which had long been known but had hitherto been rare and costly substances. Among these are titanium, beryllium, zirconium and tantalum, which are finding new uses and have such great possibilities that production is being stepped up, with the consequence that costs can be reduced and this, in turn, will make these metals available for a still wider range of applications.

Plastics have made spectacular advances. In only ten years, from 1948 to 1958, output in this country has risen from 90,000 to over 400,000 tons per annum, no small part of which finds its way into engineering. Equally remarkable has been the emergence and large-scale application, within a very few years, of completely new types of plastics. Some of these, for example, the epoxy, polyester and polyurethane groups, which are now widely used, were unknown or only just beginning to be heard of ten years ago.

All the indications are that further tremendous changes will take place in the next ten years. Hardly a month goes by without news of some new alloy, and the recent International High-Polymer Conference at Nottingham showed very clearly that scientists are still busily engaged in the search for new plastics. Work that is in the laboratory stage now may very well be influencing the engineering designer in a few years' time: to quote one instance, the announcement that certain polymers can be successfully "grafted" on to others may hold endless possibilities for the engineering industries of the future.

But further developments in materials will be determined not so much by what the metallurgists and chemists will do as by what sort of economic conditions will exist in the years ahead. Here there can be no certainty, but if the pattern of recent years is any guide there will be no slackening in the rate of technological advance—in other words, there will be a further growth of new industries, a continued high rate of mechanisation and plant renewal throughout industry and a persistent upward swing, despite occasional setbacks, in the demand for consumer durables, from cars to washing machines, which now forms such an important part of the engineering industries' output.

For the engineering designer, these events can have only one meaning—that he must produce new products, frequently re-design the old ones and all the time strive to keep costs to the minimum. In doing this he must take full advantage of the new materials—including new components—and to be well informed of design and material developments in branches of engineering other than his own.

At present, it is impossible for a designer to keep fully in touch with what is happening in materials and their application, because so much information remains unpublished, or is scattered through numerous highly specialised publications dealing with a particular product or industry and, in any case, is not usually written with the designer in mind. Again, what is being done by designers in one industry does not come to the knowledge of designers in other industries, although it may have great value for them.

It is to fill that gap in knowledge that ENGINEERING MATERIALS AND DESIGN has been brought into existence. In its articles, reports and data sheets it will provide the designer with up-to-date and authoritative information on materials and components and will also constitute a medium whereby cross-fertilisation can take place between the ideas and experiences of one branch of engineering design and another.

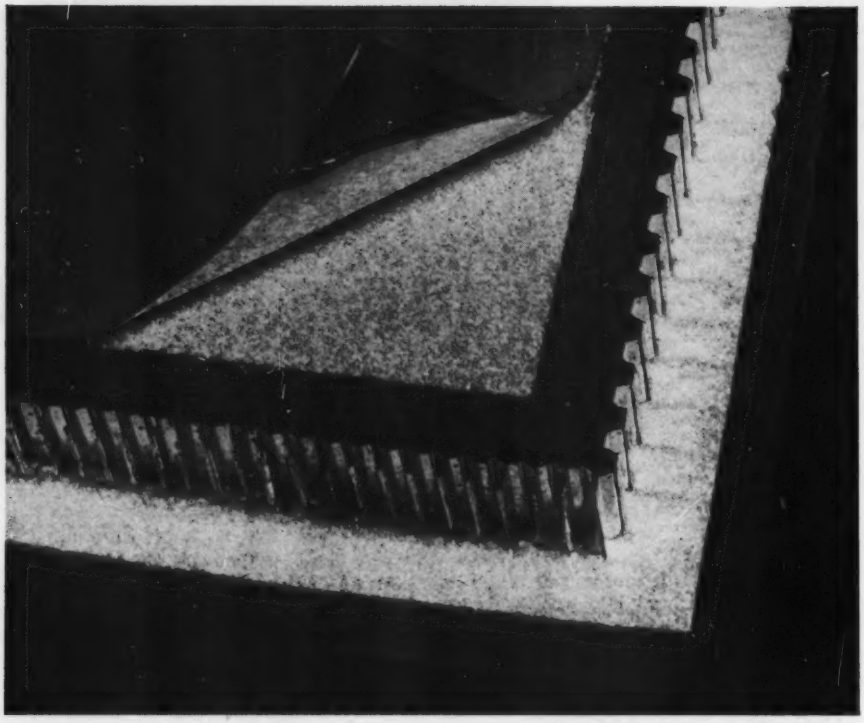


Fig. 1. "Aeroweb" honeycomb panel before bending, showing outer skins, core and Redux films.
(Photo by courtesy C.I.B.A. (ARL) Ltd.)

NEW SANDWICH MATERIAL APPLICATIONS

by A. HOLT*

The growing technique of sandwich construction is finding new uses in many fields of industry. Here are examined the possibilities of these cored materials which provide good strength-weight ratio, stiffness and insulation

IN many applications the ultimate aim of engineering designers in selecting suitable materials is to achieve optimum properties for a minimum weight which will result in operational economy and/or ease of handling. Selection on the basis of stiffness has been much in evidence particularly in airborne applications, and in widely varying industries it is gradually being realised that sandwich construction provides satisfactory answers to many problems where weight saving is necessary, but where retention of stiffness is equally important.

Sandwich construction consists (like the edible variety) of facings performing the duty of the bread and a lightweight shear-resistant core material representing the meat. Unlike the meat-and-bread combination, however, the virtue of the structural sandwich lies in the stiffness of the facings and the core as well as the effectiveness of the attachment in uniting the individual units.

To appreciate how a high degree of stiffness is achieved in a sandwich panel, consider a metal sheet placed on one edge, as indicated in Figure 3, under a compressive load the sheet will bow due to the lack of stability and bending stiffness. Assuming that the sheet is now split into two thinner sheets of equal thickness, as in Figure 4, and that these are attached each side of a lightweight core capable of transmitting shear, the result—at the cost of the extra weight of the core, and adhesive, if used—would be a sandwich panel having good bending stiffness and consequent stability under compressive loads.

The fact is that the core provides for effective stabilisation of the facing plates and, if this support has adequate shear stiffness, there is no reason why the thinnest sheet should not develop the full strength of the material in compression.

From this it is apparent that sandwich construction for structural requirements is more suitably employed in applications which are subjected to compression, flexure and torsion. Weight saving, good dimensional stability under load, clean surface appearance, elimination of internal structural support members, good thermal and acoustical insulation are a few of the advantages which this form of construction offers.

* *Head of process development department, engineering research division, A. V. Roe & Co. Ltd.*

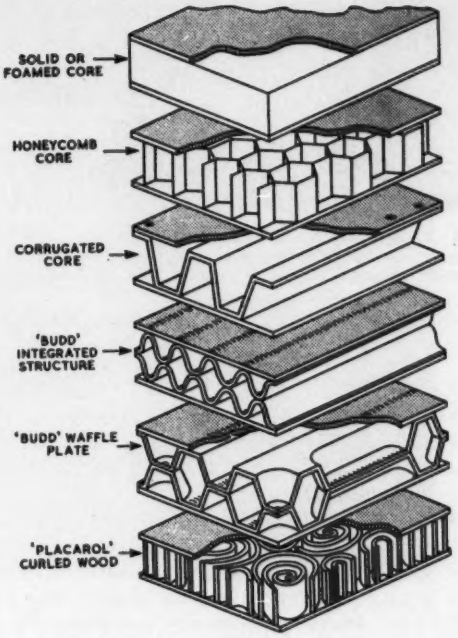


Fig. 2. Section of sandwich configurations commonly used in engineering.

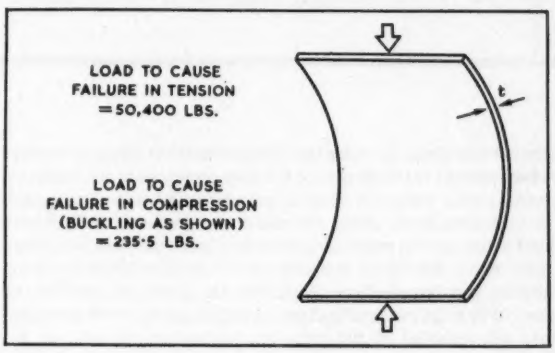


Fig. 3. Instability of single plate under compressive loading.

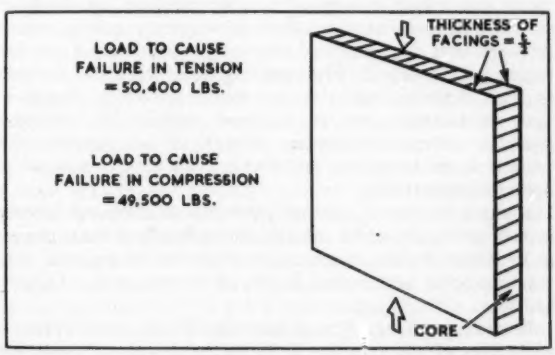


Fig. 4. Increase in compressive loading by stabilising outer skins.

Innumerable combinations of facing and core, not to mention the method of attachment, have been tried over the years, starting in 1845 with the construction of the Britannia Tubular railway bridge in North Wales, upon which the first recorded examples of sandwich construction were used. In those early days reliance was placed on conventional materials as well as conventional methods of attachment, but as the science has developed the materials and techniques have become more and more sophisticated. To say this, however, does not imply complication and difficulty. The developments mentioned have been aimed principally at reducing the weight of the sandwich panels and/or increasing the stiffness and strength, and for these considerations it is easy to see why the advances in the science have been mainly in the field of aircraft engineering, where stiffness and minimum weight are of paramount importance.

As already stated, sandwich panels, in order to be efficient, must be light and, therefore, the bulkiest part of the sandwich, namely the core, requires to be made of the lightest possible medium, or the medium, if dense, must be orientated in such a way that the major portion of the bulk consists of air (as in the honeycomb core). Any core which is going to fulfil these requirements will, in itself, be relatively fragile but, when united to the facings by efficient methods, offers the stabilising effect which allows the facings to work at high stress levels without buckling. It will be seen that the old axiom "unity is strength" is well fulfilled by sandwich structures where the individual components assembled together produce panels which are incredibly stiff by comparison with the individual materials.

The theoretical aspect of sandwich construction does not fall within the scope of this survey. The tables and graphs given on the folding sheet at the end of this article present to the designer a ready means of logically determining the material and technique to be selected for any given application. The cost of sandwich construction has recently become of greater significance with increased industrial applications, and a relative index of costs, by volume, is given in the appropriate tables.

Sandwich Combinations

In Table 1 can be seen the various cores, facings and attachment methods, as well as the suitability of particular combinations. The characteristics, such as weight, strength, stiffness and thermal conductivity, which are plainly of importance to the designer, are outlined in the tables.

Using Table 2 and the graphs in Figure 11 together, it should not be difficult to predict the properties of most honeycomb cores when it is remembered that the thermal conductivity and tensile and compressive strengths are directly related to density, and that the modulus of rigidity is substantially proportional to the value of E.

Table 3 provides the necessary basic information for the design of the face panels and examination of the contents shows that for the metals it is possible to specify precise values, but for some of the plastics and non-metals a range of values is quoted. This is particularly true of the reinforced plastics, where the reinforcement has a marked effect upon the characteristics and the range of values is very wide. It can be assumed, however, that for any particular reinforcement the values will vary in proportion to the density.

For purposes of presentation, Table 4 has been divided into two broad categories; namely, adhesive methods and mechanical methods; each of these categories is subdivided into the different types.

For the benefit of those who are unfamiliar with the newer types of adhesives, those which are mentioned in the text are considered individually below, with the salient features emphasised.

EPOXIDE—This is a very high-strength adhesive particularly suitable for metal-to-metal bonding. Dependent upon the particular activating system used, the setting up of the adhesive can be achieved either at room temperature or at temperatures as high as 200 deg. C.; for either condition, the pressure required is generally quite small and, on occasions, contact pressure only will suffice.

MODIFIED PHENOLICS—The adhesives in this group are essentially hot-setting varieties and require temperatures of

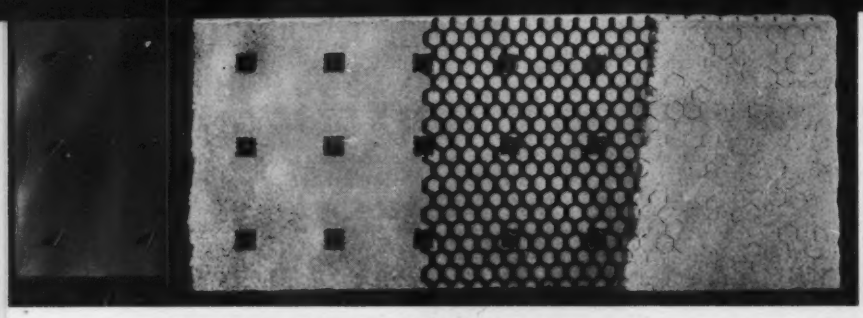


Fig. 5. Honeycomb insert filled with insulating or refractory material.
(Photo courtesy of Causeway Reinforcement Co. Ltd.)

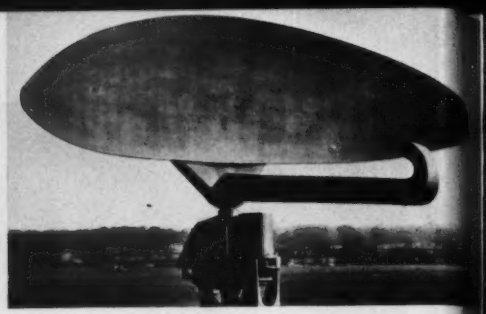


Fig. 6. Rigidity and good electrical insulation is obtained in this radar control reflector screen with resinated asbestos skins stablised with paper honeycomb. (Photo: Dufaylite Developments Ltd.)

THERMAL AND ACOUSTIC INSULATION

In this type of panel the emphasis is on the bulkiest medium, i.e., the core, because in themselves the facings, which are relatively thin, do not present a good thermal or acoustic barrier. The metal-type cores are generally undesirable and preference is given to the foamed plastics cores, followed closely by materials such as balsa wood.

Suitable for industrial refrigerator panelling; firewalls; tropical and arctic house roofing and walling; refrigerated vehicles.

ELECTRICAL INSULATION

Where rigidity is important as well as electrical insulation, these requirements can readily be met by numerous combinations of facing and core.

Suitable for high-tension switchgear; racking for electrical gear; radomes; miscellaneous electrical panels.

GOOD RIGIDITY

Panels which fall into this category are mainly metal corrugations also with metal facings, or metal or glass-cloth honeycomb cores with either metal or glass-reinforced laminate facings.

Suitable for vehicle bodies (mainly slab-sided lorries and trailers); caravan construction; aircraft structural components; radar aerials; road tankers; lightweight crates for air transport; railway wagon and coach construction; transport buildings; panelling for lifts; lightweight garage and hangar doors; boat hulls and bulkheads; self-supporting trunking; towed flight targets; external pressure vessels; ships' internal panelling and

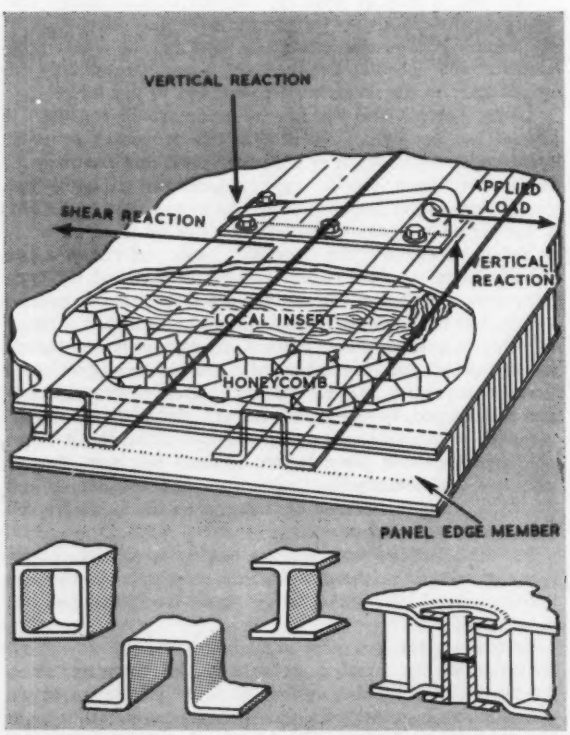


Fig. 8. Part of a honeycomb panel cut away to show local inserts for light loads. Alternatively a two-piece spool (bottom right) may be fitted under each attachment. Heavier loads require members indicated by typical sections extending to the panel edge members.

about 150 deg. C. coupled with relatively high pressures which are at least 30 p.s.i. and may be as high as 150 p.s.i. Joints made with this type of adhesive are very strong and, in addition, have good resistance to peeling loads. These adhesives can be supplied either as liquid/powder combinations or in the form of films on a fine glasscloth backing. During the curing cycle, volatiles are given off and in the case of honeycomb cells these must be perforated to facilitate the removal of the volatiles.

STRAIGHT PHENOLIC—This is a liquid phenol-formaldehyde resin normally used in conjunction with phenolic laminates and which is applied to the structure by dipping, spraying or brushing and then subsequently curing under pressure and temperature, this temperature being in the region of 150 deg. C. The resulting bond strengths are not so high as those from the epoxides or modified phenolics and, in addition, are much more brittle. The straight phenolic adhesive, however, does have one feature not present in the other two and that is the ability to withstand higher temperatures.

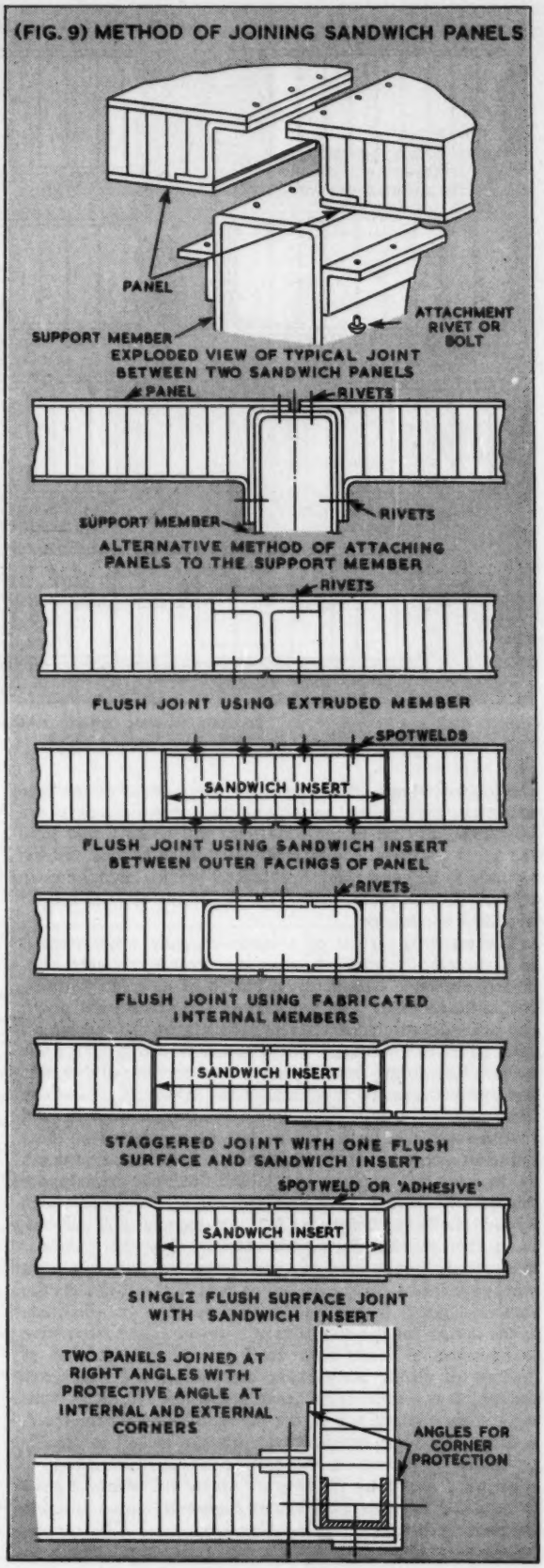
RUBBER BASED—These are generally solutions of rubber in volatile liquids which are applied by brush to the surfaces to be joined. Adhesion is brought about by solvent loss, this reaction being accelerated, if desired, by the action of slight heat.

PHENOL AND UREA FORMALDEHYDE (WOOD ADHESIVES)—Adhesives of this type are in liquid form and an activator is used to harden the adhesive in the joint, pressure being maintained during the curing cycle. These adhesives are generally used only for timber-to-timber joints and, whilst giving an adequate bond, cannot be considered in the same category as epoxides or modified phenolics.

The mechanical methods used for attachment are fairly well known, but a short review of the processes used would be useful here.

Fig. 7. Typical aircraft trailing-edge section where stiffness and preservation of contour are essential. (Photo courtesy of A. V. Roe & Co. Ltd.)

decking; lightweight ships' masts; oscillating tables for textile machines.

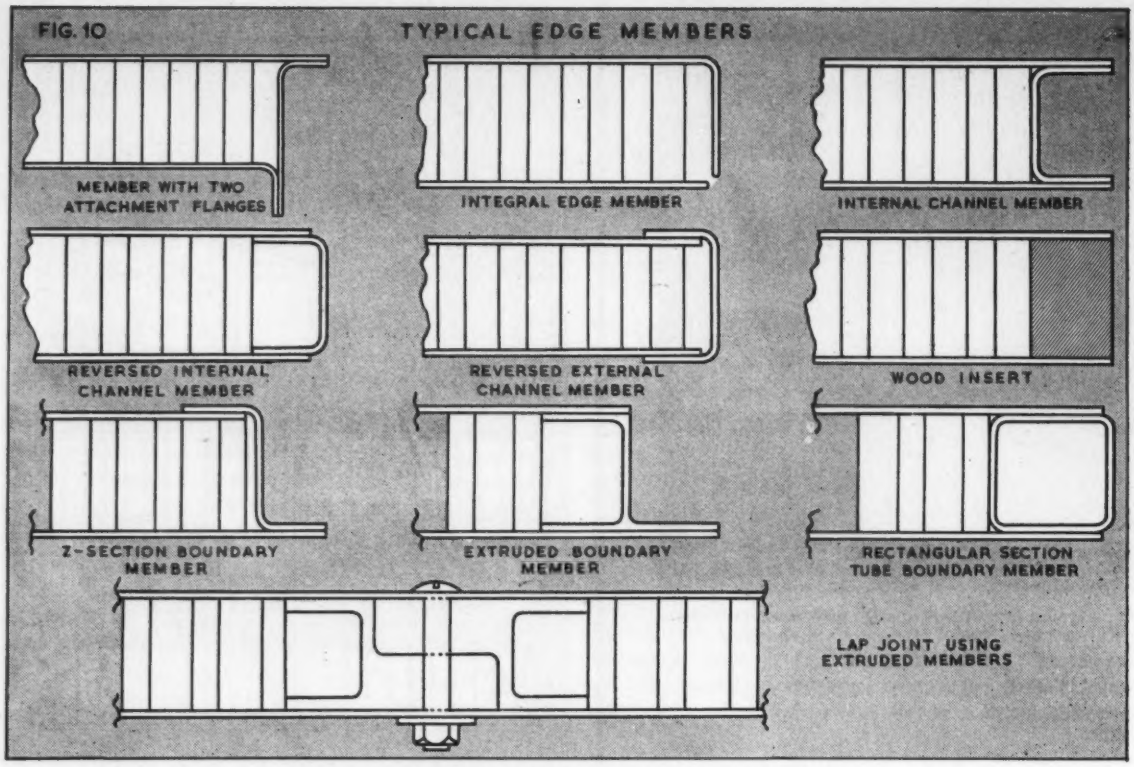

(FIG. 9) METHOD OF JOINING SANDWICH PANELS
PANEL
ATTACHMENT RIVET OR BOLT
SUPPORT MEMBER
EXPLODED VIEW OF TYPICAL JOINT BETWEEN TWO SANDWICH PANELS
PANEL
RIVETS
SUPPORT MEMBER
RIVETS
ALTERNATIVE METHOD OF ATTACHING PANELS TO THE SUPPORT MEMBER
RIVETS
FLUSH JOINT USING EXTRUDED MEMBER
SPOTWELDS
SANDWICH INSERT
FLUSH JOINT USING SANDWICH INSERT BETWEEN OUTER FACINGS OF PANEL
RIVETS
FLUSH JOINT USING FABRICATED INTERNAL MEMBERS
SANDWICH INSERT
STAGGERED JOINT WITH ONE FLUSH SURFACE AND SANDWICH INSERT
SPOTWELD OR 'ADHESIVE'
SANDWICH INSERT
SINGLE FLUSH SURFACE JOINT WITH SANDWICH INSERT
TWO PANELS JOINED AT RIGHT ANGLES WITH PROTECTIVE ANGLE AT INTERNAL AND EXTERNAL CORNERS
ANGLES FOR CORNER PROTECTION

SPOT WELDING—This consists of making a joint between two metals by the passage of a very high current through copper or copper-alloy electrodes placed either side of the joint to be made. These electrodes press the sheets firmly together under very high pressures, and the resistance to the current offered by the sheet interface is sufficient to raise the metal in the area below the electrode to melting point. The two sheets are thus fused together over an area of about $\frac{1}{8}$ in. to $\frac{1}{4}$ in. in diameter.

This outlines the process for straightforward joints. In the manufacture of sandwich panels, however, particularly those of the corrugated type, it is necessary to weld faces each side of the core; in order to pass the heavy current from one face to the other, an intermediate electrode is necessary, which may be actuated in sequence with the welding cycle so that it can be retracted to its minimum depth during passage from one spot position to the next, but extended to completely fill the corrugation space at the time the welding takes place (this device is the subject of a patent application).

SEAM WELDING—The technique for seam welding is precisely the same as that for spot welding, except that for the copper electrodes a copper wheel is used each side of the joint. Passage of the current is through the joint from the edge of one wheel to the edge of the other. The welding current is interrupted as the wheels rotate and the result is a number of welds somewhat like spot welds which are overlapped to form a seam.

BRAZING—In brazing, the metallic parts to be joined are laid together to form a sandwich and the brazing material is pre-placed in the joint areas. Thus, by the use of suitable fluxes and the application of temperatures in excess of the liquidus of the brazing material—but below that of the metallic parts being joined—the brazing material will flow into the joint areas. Therefore, during the brazing operation the brazing material is drawn by capillary attraction into



Sections showing typical methods of edging sandwich panels.

the joints and will "wet out" over the surface of the face materials. On cooling, as long as the component parts are held together, the brazing material will solidify and hold the parts together. Joints made by this technique are extremely strong and rigid. Specialised brazing techniques in respect of honeycomb sandwich structures are the subject of patent application.

The essential feature of a sandwich panel application is to carry distributed loads over the greatest possible area. Therefore, some consideration has to be given to diffusing concentrated loads into the structure at some local point; for instance, the circumstances which arise in attaching a wing panel to a fuselage. These problems can be overcome by inserting during manufacture a suitably shaped diffusion member between the two faces of the sandwich, and which is attached to the surface by the method of attachment used for the sandwich. In the case of honeycomb sandwich these diffusion members often consist of flat bars, the same depth as the core and tapering to a point. Such attachments are remarkably efficient and loads can often be applied which will fail the facing before the diffusion member will pull out.

Another problem facing the users of sandwich panels is that, subsequent to manufacture, it may be necessary to fit a heavy piece of equipment to the face of the panel. As the core is relatively fragile, and as no provision has been made in the design for the inclusion of a strong point, steps have to be taken to insert such an attachment. A number of designs for strong points have been developed which are the subject of patent application, and which rely upon drilling a suitably-sized hole in the panel followed by the insertion of a two- or three-part component which is usually assembled by the action of inserting the attachment bolt.

Figure 9 illustrates the way in which the sandwich may be attached to other panels, and Figure 10 shows suitable terminating devices for panel edge, etc.

It is most important in the case of structural panels to control the process most meticulously, because effective visual inspection of the completed panel is not possible. However, in addition to the careful control of the process, it has proved possible to inspect sandwich panels non-destructively by the use of equipment for assessing honeycomb bonds and which selectively inspects the surface of the panel.

One method of inspection is by comparing the deflection of a small area of facing with a similar panel known to possess a satisfactory bond. An example of this type of equipment has been developed by A. V. Roe & Co. Ltd. and consists of a metal tripod fitted with plastic skirting cup which may be evacuated, thus applying a differential pressure to the honeycomb facing, this pressure being directly proportional to an applied load. The deflection of the area of facing material under test is conveyed mechanically and electronically by means of a strain-gauged transducer diaphragm to an amplifier within a control cabinet which indicates on a meter set in the top of the tripod the degree of deflection, thus indicating whether the panel has been satisfactorily bonded.

A different approach to inspection of honeycomb bonding is made by the Magnaflux Corporation of America. In this method, known as Bondcheck, the surface is sprayed with a specially formulated fluid that is repelled by heat and tends to flow to the coolest area on a metal surface. By applying a controlled heat from a high-intensity infra-red lamp, the visible fluid flows to the coolest area, which is the point of attachment of the honeycomb core to the facings. Thus a complete pattern of the area is recorded on the external surface and areas of defective bond are shown as gaps in the pattern.

Two differing methods which could be used for bond inspection are fluoroscopy, where the image is viewed directly on a fluorescent screen, and by resonance using a piezo-electric crystal.

Engineering Materials and Design

NEW SANDWICH MATERIAL APPLICATIONS

DATA SHEET

Contains: Fig. 11
Tables 1, 2, 3, 4 and 5

TABLE
Suitability of various combinations of c

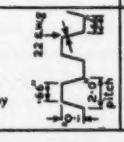
		FACINGS	Metals																						Rigid P.V.C.			
			Aluminium and Alum Alloy			Magnesium Alloy			Mild Steel			Stainless Steel			Titanium Alloy			Nimonic 100										
		ATTACHMENT	Adhesive	Welding	Brazing	Adhesive	Welding	Brazing	Adhesive	Welding	Brazing	Adhesive	Welding	Brazing	Adhesive	Welding	Brazing	Adhesive	Welding	Brazing	Adhesive	Welding	Brazing	Adhesive	Welding	Brazing		
CORES	FORM	MATERIAL																										
	Solid	Balsawood	G	N	N	F	N	N	F	N	N	P	N	N	P	N	N	P	N	N	G	N	N	G				
	Honeycomb	Resin Impregnated Paper	G	N	N	F	N	N	G	N	N	P	N	N	P	N	N	P	N	N	G	N	N	G				
	,,	Resin Impregnated Glasscloth	G	N	N	F	N	N	G	N	N	G	N	N	G	N	N	P	N	N	G	N	N	G				
	,,	Aluminium	G	N	N	G	N	N	G	N	N	P	N	N	P	N	N	P	N	N	G	N	N	G				
	,,	Mild Steel	P	N	N	P	N	N	G	N	G	P	N	P	P	N	P	P	N	N	P	N	N	F				
	,,	Stainless Steel	P	N	N	P	N	N	G	N	G	G	N	G	G	N	F	P	N	G	P	N	N	F				
	,,	Titanium	P	N	N	P	N	N	G	N	N	P	N	P	G	N	G	P	N	P	P	N	N	F				
	Cellular	Foamed Polyvinyl Chloride	G	N	N	G	N	N	G	N	N	G	N	N	P	N	N	P	N	N	G	N	N	G				
	,,	Foamed Polyurethane	G	N	N	G	N	N	G	N	N	G	N	N	P	N	N	P	N	N	G	N	N	G				
	,,	Foamed Polystyrene	G	N	N	G	N	N	G	N	N	G	N	N	P	N	N	P	N	N	G	N	N	G				
	Corrugated	Aluminium and Alloys	G	G	N	G	P	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	F				
	,,	Magnesium Alloys	G	P	N	G	P	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	F				
	,,	Mild Steel	P	N	N	P	N	N	G	G	P	F	F	P	F	F	N	P	N	N	P	N	N	F				
	,,	Stainless Steel	P	N	N	P	N	N	P	P	P	G	G	G	P	F	P	P	F	P	P	N	N	F				
	,,	Titanium Alloys	P	P	N	P	N	N	P	N	N	P	F	N	G	G	G	P	F	P	P	N	N	F				
	,,	Nimonic 100	P	N	N	P	N	N	P	N	N	P	F	P	P	F	P	G	G	G	P	N	N	P				
①	Specials	"Placarol" Curled Wood	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	G	N	N	G				
②	,,	Waffle Plate	—	G	—	—	P	—	—	G	—	—	G	—	—	G	—	—	G	—	—	—	—	—				
③	,,	Integrated	—	G	—	—	P	—	—	G	—	—	G	—	—	G	—	—	G	—	—	—	—	—				

Note:—Where welding is indicated the comments would be equally applicable to riveting.

NOTATION
G — Good
F — Fair
N — Not possible
P — Possible but not recommend
☐ — Mainly for decorative purpos
○ — Core and facings of same ma

TABLE 2
Cores for sandwich panels.

	Material	Density lb./ft.³	Flatwise Compressive Strength p.s.i.	Shear Modulus p.s.i.	Thermal Conductivity at Room Temp. cal/cm/°C/sec.
	Solid Balsa	7.0	900	17,000	.0001138
Honeycomb	Resin Impregnated Paper ¼"cell×.006"×1"	3.26	330-420	10,000	.00050
	Resin Impregnated Glasscloth ¼" cell×.003"×1"	4.2	500-1,000	18,000	.00024
	Aluminium ,, ,, ,,	5.6	380	73,000	.01536
	Mild Steel ,, ,, ,,	17.4	1,400	200,000	.00351
	18/8 Stainless Steel ,, ,, ,,	17.2	2,300	213,000	.00128
	Ti 150 Titanium ,, ,, ,,	9.65	1,700	106,000	.00132
	Nimonic 100 ,, ,, ,,	17.8	2,500	230,000	.00224
Cellular	Foamed Polyvinylchloride	5-10	30-130	—	.000083 App.
	Foamed Polyurethane	4-8	50-225	—	.000072 App.
	Foamed Polystyrene	1.8-4.5	20-140	—	.000086 App.
Corrugated	Aluminium Alloy	8.4	—	195,000*	.00896
	Magnesium Alloy	5.4	—	135,000*	.01064
	Mild Steel	24.5	—	500,000*	.00336
	18/8 Stainless Steel	24.2	—	565,000*	.00112
	FV 520 Stainless Steel	24.2	—	565,000*	.00102
	Ti 150 Titanium	14.2	—	352,000*	.00114
	Ti 318A Titanium Alloy	14.5	—	360,000*	.000504
	Nimonic 100	25.1	—	647,000*	.00196



* In the direction of the Corrugations

Facings f

Material		Ultimate Tensile Strength psi	0.1% Proof Strength psi	Young's Modulus psi × 10⁶
Aluminium (Hard Rolled)		18,000	—	9.9
Aluminium Alloy		61,000	47,000	10
Magnesium Alloy		38,000	24,600	6.4
18/8 Stainless Steel		117,000-156,000	90,000-112,000	25.8
FV520 Stainless Steel	(1)	145,000	137,000	27.2
Titanium T. 150		80,000	67,000	15
Titanium 318A		140,000	127,000	15
Nimonic 100		180,000	119,000	31
Medium Carbon Steel		63,000	36,000	29
Cotton Fabric Rein. Phenolic		13,000-19,000	—	—
Glass Fabric Rein. Phenolic	(2)	15,000-35,000	—	—
,, ,, ,, Polyester	(2)	20,000-50,000	—	—
,, ,, ,, Epoxide	(2)	15,000-70,000	—	—
,, ,, ,, Silicone	(2)	11,000-30,000	—	—
Acrylic Sheet		9,000	—	0.45
Rigid P.V.C. Sheet		4,000-8,000	—	0.45-0.6
Styrene Copolymer Sheet	(4)	5,000-12,000	—	0.4-0.5
Asbestos Reinforced Phenolic		18,000	—	1.7
Paper Reinforced Phenolic		13,500	—	—
Wood Veneer Laminate	(3)	17,000	—	—
Asbestos Sheet		2,200	—	1.5
Plywood		—	—	1.1
Glass Sheet		—	—	10-11
Hardboard		—	—	—

(1) Firth Vickers Ltd. (2) Type of Glass Reinforcement profoundly affects properties

TABLE I

Suitability of various combinations of cores, fa

| FACINGS | | Metals | | |

cores, facings and attachments.

Plastics																												Timbers				Others			
Styrene Copolymer Sheet			Acrylic Sheet			Reinforced Plastics: Glass Fabric/ Polyester			Paper or Glass or Cotton Fabric/ Phenolic			Glass Fabric/ Epoxide			Glass Fabric/ Silicone			Asbestos Reinforced Phenolic			Plywood			Hardboard			Asbestos Board			Sheet Glass		
Adhesive	Welding	Brazing	Adhesive	Welding	Brazing	Adhesive	Welding	Brazing	Adhesive	Welding	Brazing	Adhesive	Welding	Brazing	Adhesive	Welding	Brazing	Adhesive	Welding	Brazing	Adhesive	Welding	Brazing	Adhesive	Welding	Brazing	Adhesive	Welding	Brazing	Adhesive	Welding	Brazing
G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	P	N	N	P	N	N
G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	P	N	N	G	N	N	G	N	N	G	N	N	P	N	N	G	N	N
G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	F	N	N	G	N	N
G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	F	N	N	G	N	N
P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	G	N	N	G	N	N	P	N	N	P	N	N	G	N	N	P	N	N
P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	G	N	N	G	N	N	P	N	N	P	N	N	G	N	F	P	N	N
P	N	N	P	N	N	P	N	N	F	N	N	P	N	N	G	N	N	G	N	N	P	N	N	P	N	N	P	N	N	P	N	N
G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	P	N	N
G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N
G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	G	N	N
P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N
P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N
P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	G	N	N	P	N	N	P	N	N	G	N	N	P	N	N
P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	F	N	N	P	N	N	P	N	N
P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N	P	N	N
G	N	N	G	N	N	G	N	N	G	N	N	G	N	N	P	N	N	P	N	N	G	N	N	G	N	N	F	N	N	N	N	N
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

① F. Hill & Sons Ltd.
② The Budd Co. U.S.A.
③ Turner Bros. Asbestos, Ltd.

nded
oses
aterial

TABLE 3

for sandwich panels.

Flexural Strength psi × 10^3	Flexural Modulus psi × 10^6 approx	Density lb./in.^{3}	Coefficient of thermal Expansion per °C × 10^{-6}	Thermal Conductivity c.g.s. units	App. Cost Index (by vol.) Aluminium = 1
—	—	0.0975	24	0.502	1.0
—	—	0.101	23	0.32	1.5
—	—	0.065	29	0.20	2.9
—	—	0.286	16.9	0.036	4.0
—	—	0.282	11.3	0.043	5.75
—	—	0.163	8.19	0.04	50.0
—	—	0.160	9.4	0.04	75.0
—	—	0.290	12.4	0.028	20.0
—	—	0.286	11.0	0.12	0.75
20-26	1	0.047-0.051	10-25	6-9 × 10^{-4}	1.5
18-40	2.2	0.061-0.075	—	—	Varies
20-70	2.2	0.061-0.075	—	—	Varies
20-90	3.5	0.061-0.075	—	—	Varies
13-30	—	0.061-0.075	—	—	Varies
—	—	0.043	87	3.5 × 10^{-4}	2.5
—	—	0.049-0.056	80	3-7 × 10^{-4}	0.87
—	—	0.037-0.039	60-80	2-3 × 10^{-4}	—
—	—	0.06	24	18 × 10^{-4}	0.45
19	1	0.05	10-25	6-9 × 10^{-4}	0.47
13	1.5	0.035	11	3.5 × 10^{-4}	0.6
6.25	—	0.069	8	15 × 10^{-4}	0.62
—	0.3-0.6	0.022	5.4	4 × 10^{-4}	2.0
—	—	0.095	8.7	25 × 10^{-4}	0.49
—	—	0.055	10	7-9 × 10^{-4}	0.19

ties and cost. (3) "Hydulignum": Hordern-Richmond Ltd. (4) "Ferobestos": J. W. Roberts Ltd.

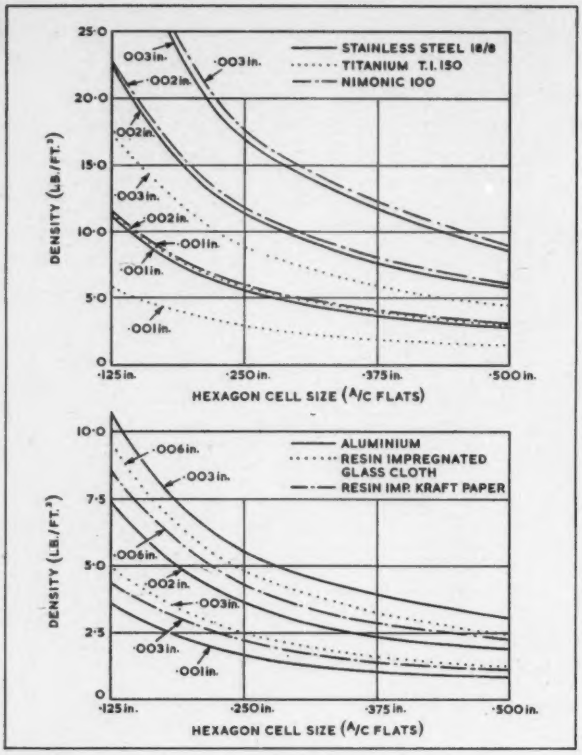


Fig. 11. Honeycomb core densities.

Core	Facing	Method of Attachment		F
Solid Balsa	Plywood	Phenol or Urea-Formaldehyde	A	Normal woodwor
Res. Imp. Paper Honeycomb	Plywood	Phenol or Urea-Formaldehyde	A	Dip core edges an adhesive
,, ,, Glasscloth	Alum. Alloy	Epoxide (hot set)	A	,, ,,
,, ,, ,, ,,	Polyester/ Glass Fibre	Polyester	A	Use facing lam adhesive
,, ,, ,, ,,	Asbestos/ Phenolic	Epoxide (hot set)	A	Dip core edges an adhesive
Aluminium Honeycomb	Alum. Alloy	Epoxide (hot set)	A	Dip core edges an adhesive
,, ,,	Alum. Alloy	Modified Phenolic	A	Dip core edges an liquid adhesive pl
,, ,,	Paper/Phenolic	Epoxide (cold set)	A	Dip core edges an adhesive
,, ,,	Plywood	Epoxide (cold set)	A	Dip core edges an adhesive
,, ,,	Sheet Glass	Acrylic	A	Coat edges of adhesive
Carbon Steel Honeycomb	Carbon Steel	Copper/Silver	B	Assemble compon foil between core fluxes necessary
,, ,, ,,	Asbestos Board	Straight Phenolic	A	Dip core edges an adhesive
Stainless Steel Honeycomb	Stainless Steel	Copper/Silver	B	Assemble compo foil between core flux necessary
Titanium Honeycomb	Titanium Alloy	Special Alloy	B	Experimental Tec
Foamed Polyvinylchloride	Rigid P.V.C.	Synthetic Rubber	A	Apply adhesive t and assemble
Foamed Polyurethane	Paper/Phenolic	Synthetic Rubber	A	Apply adhesive t and assemble
Foamed Polystyrene	Copolymer Styrene Sheet	Synthetic rubber	A	Apply adhesive t and assemble
Corrugated Al. Alloy	Alum. Alloy	Spot	W	
,, Mag. Alloy	Magnesium Alloy	Spot	W	Assemble cor
,, Carbon Steel	Carbon Steel	Spot	W	and spot wel
,, Stainless Steel	Stainless Steel	Spot	W	facings by spo
,, Titanium Alloy	Titanium Alloy	Spot	W	intermediate
,, Nimonic 100	Nimonic 100	Spot	W	
Curled Wood	Plywood	Urea-Formaldehyde	A	Apply adhesive assemble

A=Adhesive. B=Brazing. W=W

TABL

Attachment

	Type	Surface Prep. Required	
Adhesive Methods		Metals—Chemical Etch	Can be used in liqui form for hot curing
	Epoxide	Plastics—Abrade	Best adhesive for fi
	Phenolic	Plastics—Abrade	Generally requires
	Modified Phenolic	Metals—Chemical Etch	Heat and pressure
	Phenol or Urea-Formaldehyde	None	Applied in an aque Sometimes heated
	Rubber Base	Freedom from Grease. Generally none required.	Applied as a solut simplifies assembly.
Mechanical Methods	Spot Welding	Chemical etch or scratch Brush	Specialist equipm achieved. Gives
	Seam Welding	" "	
	Riveting	None	Small capital outla good attachment e
	Brazing	High degree of cleanliness required usually achieved with chemical etch.	Highly specialised materials are costly

* This ignores ca

TABLE 5

Properties of various sandwich panels.

Processing Comments			Stiffness Index	Strength Index			Maximum Service Temp.	Flam
	Temp	Pressure		Static	Fatigue	Creep	Approx.	
l woodworking practice	—	—	F	G	G	P	70°C	Burns r
re edges and coat facings with e	Room	Light	G	G	G	P	70°C	Burns r
" " "	150°	Light	G	G	G	F	100°C	Facing p
acing laminating resin as e	100°C	Light	G	G	G	P	70°C	Burns r resin is
re edges and coat facings with e	150°C	Light	G	G	G	F	110°C	Burns s
re edges and coat facings with ve	160°C-200°C	Light	E	E	G	F	110°C	Good r
re edges and coat facings with dhesive plus powder	150°C	Moderate	E	E	G	F	100°C	Good r
re edges and coat facings with e	Room	Light	F-G	G	G	P	70°C	Facing
re edges and coat facings with e	Room	Light	F-G	G	G	P	70°C	Burns r
edges of core only with e	Room	Contact	—	—	—	—	—	With h cal da
ble components with brazing tween core and facing. Special necessary	700°C	Light	E	E	G	E	300°C	Excelle
re edges and coat facings with ve	150°C	Moderate	G	F	P	P	150°C	Excelle
ble components with brazing tween core and facings. Special cessary	650°C 700°C	Light	E	E	G	E	300°C	Excelle
mental Technique	600°C+	—	E	E	G	E	300°C	Excelle
adhesive to core and facings semble	Room	Contact	F	F	G	P	70°C	Self ex
adhesive to core and facings semble	Room	Contact	F	F	F	P	70°C	Facings
adhesive to core and facings semble	Room	Contact	F	F	G	P	70°C	Burns
semble corrugation to facing l spot weld. Attach other ngs by spot welding using an rmediate electrode.	— — — —	— — — —	E E E E	E E E E	E F G E	G G G E	150°C 150°C 300°C 400°C 400°C 800°C	Excelle (1) Go Excelle Excelle Excelle Excelle
adhesive to facings and ble	100°C	Moderate	F	G	F	P	70°C	Burns

g. W=Welding. R=Riveting. E=Excellent. G=Good. F=Fair. P=Poor. (1) Burns fiercely, if

TABLE 4

Attachment methods.

	Surface Prep. Required	Processing Features	Cost Index (by vol) 1=Cheapest
	Metals—Chemical Etch	Can be used in liquid form or paste form for cold curing and solid or powder form for hot curing. Only contact pressure is necessary.	
	Plastics—Abrade	Best adhesive for fillet forming.	5
	Plastics—Abrade	Generally requires heat and pressure for Curing.	2
c	Metals—Chemical Etch	Heat and pressure essential for curing. Available in solution form or in film.	4
de	None	Applied in an aqueous solution. Only assembly pressure required. Sometimes heated to assist cure.	1
	Freedom from Grease. Generally none required.	Applied as a solution. Contact pressure only required. High "tack" simplifies assembly.	3
	Chemical etch or scratch Brush	Specialist equipment required. Very high rates of production can be achieved. Gives very high attachment efficiency.	1*
	" "		2*
	None	Small capital outlay. Relatively speedy. Depending upon rivets used, a good attachment efficiency is realised.	3
	High degree of cleanliness required usually achieved with chemical etch.	Highly specialised techniques needed to guarantee reliability. Brazing materials are costly.	4

* This ignores capital equipment.

ABLE 5

rious sandwich panels.

	Stiffness Index	Strength Index			Maximum Service Temp.	Flammability	Cost Index (by vol)	Special Features
e		Static	Fatigue	Creep	Approx.		Alum. Alloy Honeycomb=1	
	F	G	G	P	70°C	Burns readily	0.32	Mainly used for flat panels.
	G	G	G	P	70°C	Burns readily	0.33	May be used without specialist equipment.
	G	G	G	F	100°C	Facing protect core	1.14	Good thermal insulation with serviceable facings.
	G	G	G	P	70°C	Burns readily unless resin is treated	1.83	Used for radar transparencies.
	G	G	G	F	110°C	Burns slowly	1.08	Excellent thermal insulation
	E	E	G	F	110°C	Good resistance	1.00	Good structural material
te	E	E	G	F	100°C	Good resistance	0.90	Good structural material.
	F-G	G	G	P	70°C	Facing protects core	0.66	Useful for light duty and decorative panelling.
	F-G	G	G	P	70°C	Burns readily	0.69	" " " " " " "
t	—	—	—	—	—	With heat, mechanical damage results	0.38	Excellent decorative material.
	E	E	G	E	300°C	Excellent resistance	4.44	Technique requiring specialist knowledge and equipment.
te	G	F	P	P	150°C	Excellent resistance	0.60	Would make a good fire barrier.
	E	E	G	E	300°C	Excellent resistance	6.00	Excellent structural material for elevated temp. use.
	E	E	G	E	300°C	Excellent resistance	120.00	Experimental—still under development.
t	F	F	G	P	70°C	Self extinguishing	0.30	Excellent thermal insulation at low temperatures.
t	F	F	F	P	70°C	Facings burn readily	0.30	" " " " " "
t	F	F	G	P	70°C	Burns readily	0.30	" " " " " "
	E	E	E	G	150°C	Excellent resistance	0.90	Good structural material for flat on single curvature panels
	E	E	F	G	150°C	(1) Good resistance	1.80	" " " " " " " " "
	E	E	G	G	300°C	Excellent resistance	0.72	" " " " " " " " "
	E	E	E	E	400°C	Excellent resistance	2.64	" " " " " " " " "
	E	E	G	E	400°C	Excellent resistance	43.20	" " " " " " " " "
	E	E	—	E	800°C	Excellent resistance	11.76	" " " " " " " " "
te	F	G	F	P	70°C	Burns Readily	0.24	Good thermal insulation and decorative properties.

llent. G=Good. F=Fair. P=Poor. (1) Burns fiercely, if ignition temperature is reached.

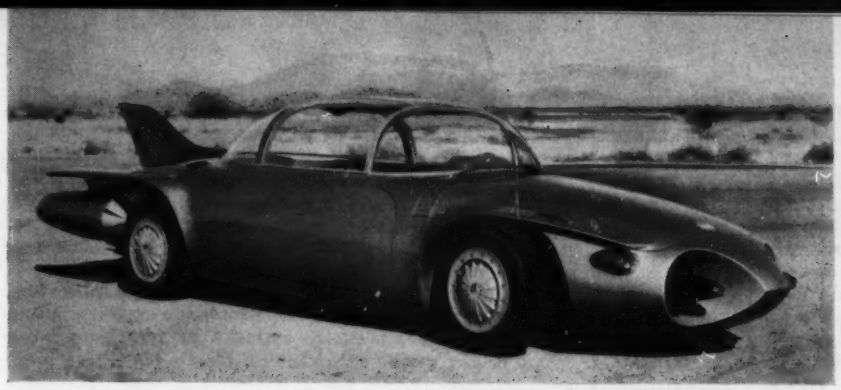


Fig. 1. Titanium-bodied gas-turbine powered car—Firebird II. (Photo courtesy of General Motors Corp.)

EXTENDING THE USES OF TITANIUM

Titanium has become well established in the aircraft industry. In this article the characteristics of the metal are outlined, recent developments are described and the possibilities of applying it more widely in engineering are examined

NO other metal has received more publicity in recent times than titanium. The element was discovered 167 years ago, but only in the last ten to twelve years has it risen to its present position of importance, largely through the interest taken in it by the aircraft industry. The current recession in and the reorientation of that industry raises the question of the future of the metal and makes it necessary to probe beneath the glamour which surrounds it.

It is important to consider how far it satisfies the basic needs of designers in engineering industries outside aircraft manufacture, those needs being high specific mechanical properties, ability to be fabricated and machined with the minimum of preparation and specialised equipment, and a cost as low as is consistent with the properties necessary for its particular application.

Before an impartial evaluation can be made it is necessary to define clearly the salient features of titanium. Of these, the most important to the engineering industries is its high cost, which is due to the difficulties of extracting and subsequent processing. If the demand were such that producing units could work to full capacity, the cost of mill products could be reduced by as much as 50 per cent, but until prices fall the demand will be held in check. Imperial Chemical Industries Ltd. and Wm. Jessop & Son Ltd. have made a series of price reductions, the latter offering special terms to users who are experimenting and developing manufacturing techniques. These are practical steps in the right direction, and should enable titanium to gain a foothold in industries not at present disposed to give it much thought. The price of titanium has dropped from approximately £18,000 per ton in 1950 to £7,000 per ton, but it is still extremely expensive.

It is obvious that a titanium part will not be substituted for one in a conventional material unless it offers greatly improved physical and mechanical properties, considerably longer life, lower maintenance costs, lower fabrication costs, or a combination of all four. In many applications it can meet those requirements, but probably more important than the substitution of titanium for existing materials are the entirely new fields of application.

Before dealing in detail with the mechanical and physical properties of titanium and their relation to the application of the material, it is desirable to mention the three well-known solid phase relationships in which the metal exists metallurgically. These are the low-temperature form with hexagonal close-packed crystal structures known as alpha titanium (α), the high-temperature form above 882·5 deg. C. with body-centred cubic structure known as beta titanium (β) and a combination of alpha and beta known as the alpha + beta ($\alpha + \beta$).

The metal at present offered to industry falls into the alpha group, which contains the commercially pure titanium of high ductility, and the alpha + beta group, which are strong but difficult to fabricate. The beta titanium is inherently unstable, but for this group of alloys there is undoubtedly a future if and when sufficient development work has been carried out to reduce their brittleness at high temperatures, and they should then exhibit a very high strength at elevated temperatures, with an improved resistance to corrosion.

Attractive Strength/Weight Ratio

For the aircraft industry the greatest attraction is its strength-to-weight ratio at room and elevated temperature. About half the density of steel, it has a relatively low modulus of elasticity which varies from 15 to 17 $\times$ 10^6 p.s.i.

Structural rigidity may be increased by recourse to sandwich construction which, with modern techniques in resistance welding and adhesives, allows a high shear flow to be realised.

Weight saving is not confined to the aircraft industry. Where a high acceleration or velocity is required in prime movers and mechanisms, titanium can be attractive, since for the same effort acceleration is inversely proportional to mass. In this sphere the applications of titanium are widely diverse, covering such components as high-speed camera

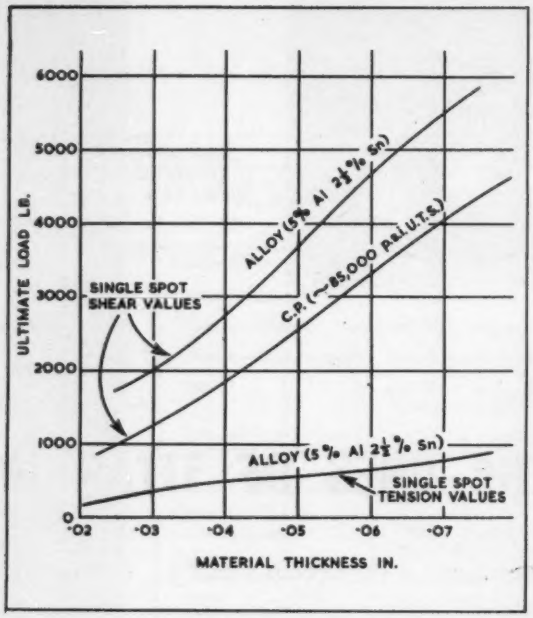


Fig. 2. Strength of spot weld in titanium.

shutters, instruments, connecting rods in racing-car engines, and parts of gas turbines.

Where elevated temperatures are encountered the alloys show a high degree of strength up to approximately 500 deg. C., after which there is a fairly rapid drop. The strength of the commercially pure titanium declines more uniformly as shown in Figure 3, but at a lower level of strength.

In common with most other metals, titanium is notch sensitive, but at room temperatures it exhibits a high fatigue strength, provided the surface is carefully prepared and is free from defects. From the S/N curve in Figure 4, it will be noted that the fatigue limit is well defined, the curves thereafter running practically parallel to the base line. This characteristic should be of advantage to the designer, as the fatigue life is practically independent of the number of reversals when the working stress is below the lower limit defined by the S/N curve.

Titanium thus has an advantage over steel and light alloys where fatigue is a consideration, and relative to the number of reversals, the high stress at which it may be worked may well outweigh its initial cost. Typical examples of this are titanium springs (see Figure 5), but note should be taken of the low E value and the surface condition of drawn wire. The latter condition may be improved by sheathing the titanium in copper before drawing, thus protecting the surface and assisting to prevent the inclusion of impurities at elevated temperatures.

An examination of the creep properties reveals one of the disadvantages of titanium, since the commercially pure material undergoes creep even at normal room temperatures, although cold working will improve its resistance. The creep resistance has a direct relationship to ductility but, in general, creep problems are not met with parts made from commercially-pure titanium.

The titanium alloys show a significantly improved resistance to creep, and many are specially developed for this purpose. For such examples as a turbine disc the gain by using titanium is accumulative. Because of its lightness, the centrifugal forces, and therefore the stresses, are reduced, thus contributing to a further reduction of material.

When in rubbing contact titanium shows a marked tendency towards localised pressure welds and to "pick-up". Among the various treatments which may be given to prevent this action are molybdenum disulphide lubricants, electroplating chrome or molybdenum, case-hardening by heating in nitrogen or ammonia (depth up to 0·001 in.) and by the Albright & Wilson Kanigen non-electrical process and the I.C.I. Sulfinuz process.

Titanium exhibits one of its greatest potentials (see Figure 6) in its corrosion resistance. It is highly resistant to most corrosive liquids and can be further improved

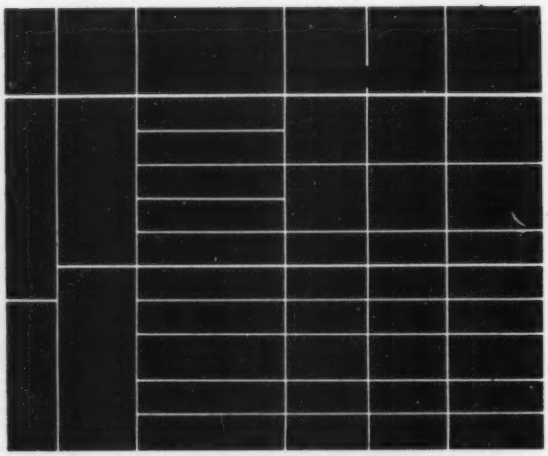


TABLE I. Titanium available to industry.

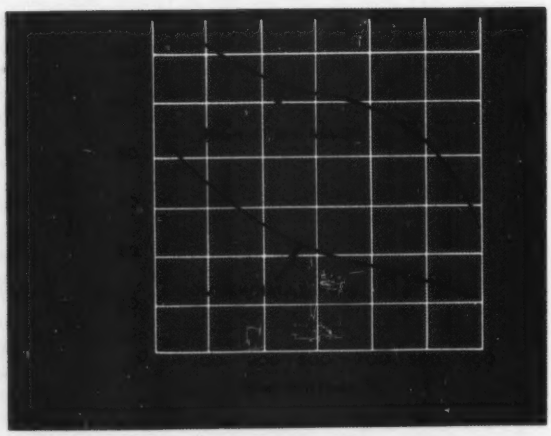


Fig. 3. Variation of ultimate tensile strength with temperature.

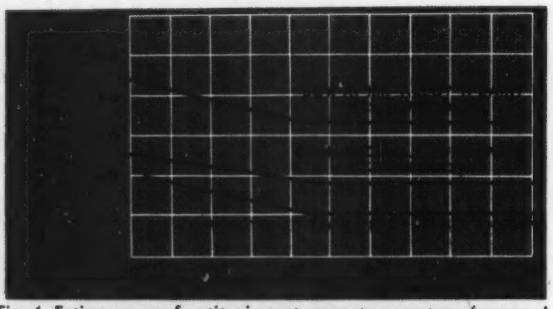


Fig. 4. Fatigue curve for titanium at room temperature (reversed direct stresses).

by raising the electrical potential of the titanium above that which would be normally attained in a corrosive medium.

Though heat transference has been much improved where titanium has replaced such materials as rubber, ceramics, plastics and glass, thermal conductivity is only one of the variables. In many cases the controlling variable may be the characteristics of the protective oxide film of the metal or of the corrosion products, and under these conditions titanium may be the most efficient material. An example of this is the jacketed kettle shown in Figure 7.

An additional consideration which allows titanium to contribute to the thermal efficiency of a system is that the engineer may specify thinner sections. Higher strength, lower corrosion rates and titanium's freedom from stress corrosion cracking make such design modifications possible.

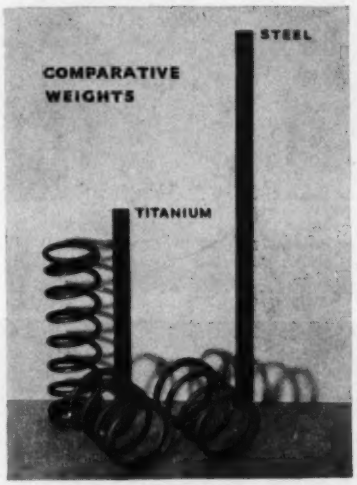
Welded joints in most of the alpha-beta alloys are, however, brittle, even when contamination is negligible, and subsequent heat treatment will not fully restore the original properties.

The formation of sound spot welds in the commercially-pure and in the alloys is a straightforward operation using conventional equipment, provided the work surface is absolutely clean. The strength of these welds is indicated by curves in Figure 2.

Extrusions are possible and, depending on complexity, may be produced free from any coarse boundary layer of indifferent mechanical properties.

Castings, though technically possible, are not yet a commercial proposition as special moulds and the need to carry out the casting *in vacuo* make the present cost prohibitive.

Drop forgings are widely used in the aircraft industry and may be produced satisfactorily, but again the cost must be considered, together with reduced die life, because of the lower temperatures and consequent higher pressures. Where size and shape demand high forging temperatures, an increase in grain size is inevitable, although this can be reduced by successive working.



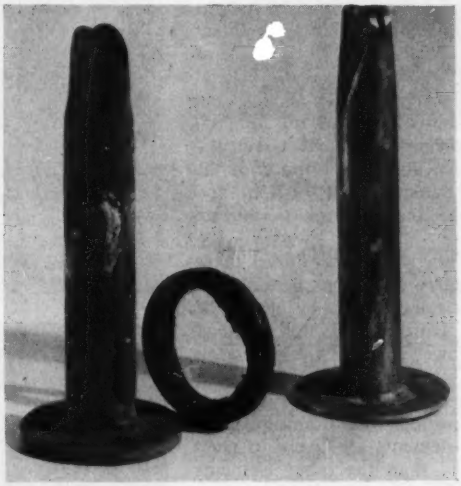
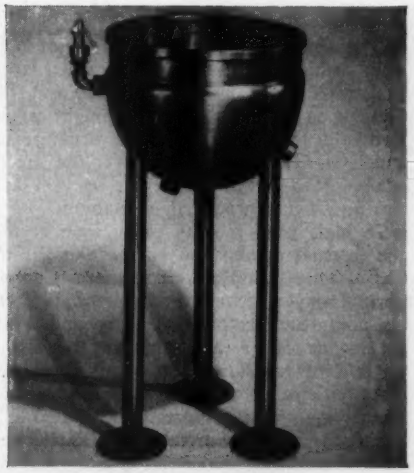


Fig. 5 (*extreme left*). Titanium springs. (Photo courtesy of Herbert Terry & Sons Ltd.)

Fig. 6. Gas/liquid nozzles. Left—a mild steel nozzle after a few days' service; right—I.C.I. titanium nozzle of two months' service.

Fig. 7. Five-gallon steam-jacketed kettle in titanium, 40 p.s.i. working pressure. (Photo courtesy of B. H. Hubbert & Son Inc.)



Recent Developments

Powder Metallurgy

Powder metallurgy at one period was considered as a method of producing titanium more cheaply; although out of favour at present, it still offers possibilities, since it compacts very well. High pressures are required and consequently dies are expensive, but for a long production run there could be an ultimate saving. Limits on sintered parts can be maintained at $\pm\frac{1}{16}$ in. and their strength is comparable to parts made from arc-melted titanium. Components made by powder metallurgy methods show a definite saving of basic titanium sponge: 1·7 lb. of sponge will produce a 1-lb. finished machined part by sintering, whereas 8 lb. sponge may be required for a 1-lb. part produced by melting, forming and machining. All sintering must be done *in vacuo*.

Foil

In this country, foil can now be produced in a thickness as low as 0·002 in. for the commercially-pure and 0·015 in. for alloy titanium. This offers, together with newly-developed techniques for resistance welding of sandwich construction, an all-titanium constructional material inherently stiff, strong, and with a resistance to corrosion for a low weight. The American Silver Co. Inc. claims to have produced foil in the form of 8-in. wide strip to a thickness of 0·0005 ±0·0001 in.

Cladding

The clad materials, as distinct from a lining material, offer reduced cost, both on raw material and in fabrication, for at present many components (cylindrical containers) are lined with titanium which, in effect, is doing one job twice over. To produce the clad materials titanium is rolled with a base metal within a copper sheath to exclude any contaminating elements, to form in effect a single sheet, each metal retaining its own property. Certain

deleterious inter-metallic compounds may be formed, however, which may affect the adherence of titanium to the base metal when forming.

SHEATH ROLLING

This process enables a higher rolling temperature to be used without risk of contaminating the heated titanium which is enclosed between two sheets of a base material, such as copper, the edges of which are sealed. The advantages of such a process are rather negated by having to strip off the base metal after the final roll, but no doubt research will simplify this operation.

PLATING

Plating titanium on to a base metal to give a corrosion-resistant coating has, according to American sources, been successfully carried out and this may be a development which will have considerable applications until the price of titanium can be reduced.

A process of flame spraying titanium particles has a big advantage in that the piece to be coated does not appreciably rise in temperature under the process, but it is necessary to etch the surface to ensure absolute adhesion of the coating. At present, even with thicknesses of 0·001 in. and upwards, the coating is porous and must be taken into account.

Vapour-deposited coatings previously mentioned have limitations set by the need to carry out the process at high temperatures which, in some instances, may be above the transition point of titanium. Diffusion of the coatings, which may be porous, may, however, affect the properties of the titanium.

Diffusion coatings and interstitial dispersion are not likely to be a practical proposition with titanium, since with the latter the interstitial elements are likely to react with the titanium more readily than the other elements which could be alloyed with it.

Applications

The aircraft industry was the major outlet for titanium and, within its present commitments, large quantities are still used, both in the airframe and the power units. Bearing in mind the need for weight saving in this sphere (where 1 lb. weight saved on structure can represent as much as £1,000 in revenue over the life of a large aeroplane), load-carrying fasteners as well as nuts and bolts are now being produced in titanium.

In high-speed moving parts, such as may be found in the internal combustion engine and gas turbine, titanium has already found a limited place. Compressor blades at certain stages are almost commonplace (Figure 9), while the compressor rotor of the Pratt and Whitney J-57 turbo-jet engine is an all-titanium assembly. A few British engines carry all-titanium rotors, but increased cost has not been considered worth the advantages gained. Titanium connecting rods have already been used in a certain British racing-car engine, but this latter application is unlikely to be extended to commercial engines.

The largest potential outlet for titanium is in the chemical and food industry where the absence of contamination makes possible new chemical reactions formerly impractical on an industrial scale.

A typical component used in the chemical industry is an impeller for a plant leaching cobalt arsenic sulphide concentrates at high pressures in temperatures of 200 deg. C.; this outlasted impellers made from other materials in the ratio of four years to a few hours.

Typical uses in the marine world would be propellers, stabilisers and rudders on small craft, where reduced maintenance and power requirements would be the benefit. Whereas these components previously may have been cast, the process of fabrication could be advantageous. Experimental propellers have, in fact, been considered and made, and one may expect to hear more of this in the future.

Fig. 8. Pressure tanks made from two hemispherical spinnings welded together for the Atlas missile and the North American Aviation X15 research aircraft. (Photo courtesy of Titanium Metal Corp. of America.)

Fig. 9. All-titanium compressor rotor for J-57 Pratt & Whitney turbo-jet. (Photo courtesy of Titanium Metals Corp. of America.)

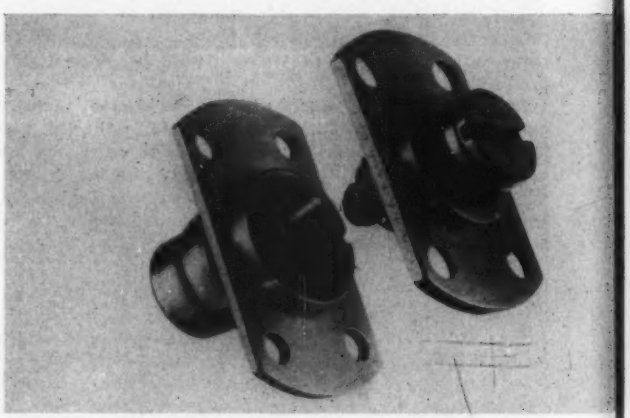


Fig. 10. Quick-release titanium load-carrying fastener. (Photo courtesy of King Aircraft Corp.)

Fig. 11. Titanium yacht anchor weighing 20 lb., and 44 per cent lighter than its equivalent in steel. (Photo courtesy of Mallory-Sharon Metals Corp.)

Fig. 13. Thermo-couple using titanium as an intermediary between stainless-steel probe and finned magnesium-alloy casing. (Photo courtesy of British Welding Research Assoc.)

The applications to marine instruments and parts subjected to sea spray provides a fertile medium for development.

High-speed shutter mechanisms for cameras provides another example of the possibilities for titanium, while vessels made from the metal are being used in the photographic processing industry and cause less contamination to the liquid they contain than the steel vessels previously used.

In nuclear engineering titanium has been used for manipulating equipment partly because of its low weight and mechanical properties and partly because it has a short half-life after irradiation.

One of the most recent applications of titanium is in a thermocouple for measuring the temperatures of the fuel elements in its nuclear reactors. This has introduced the problem of making a gastight joint between the stainless-steel-sheathed thermocouple and the finned fuel element container made of magnesium alloy. Figure 13 shows a method in which an intermediate metal, titanium, is used. Stainless steel can be joined to the alloy by direct brazing, but the joint is inadequate at the working temperatures. A titanium stud was formed on a titanium disc resistance welded to the magnesium end cap and, after the stud had been drilled, the stainless-steel sheath was inserted and high-frequency brazed to it in an inert atmosphere using silver solder.

In the American car industry titanium has been used experimentally for the exhaust systems where heat, water and exhaust gases necessitate a frequent replacement of these parts when made from conventional materials.

A further development is the production of expanded mesh which may have applications in filters, and where a metallic bonding agent is required in ceramics. This may also take the form of a textured metal which, in addition to being used in a decorative sense, obviously has uses in such components as cores for fabric-type filters and shrouds for jet engines where the additional stiffness imparted by the pattern is an advantage. Titanium in the form of pure wire mesh is already being used quite extensively in the chemical industry.

Acknowledgment is made to British and foreign titanium producers and users for certain information in this article.

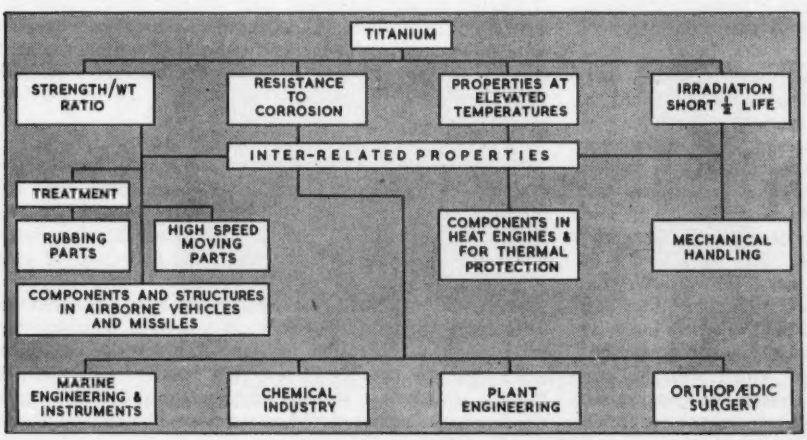


Fig. 12. Properties and applications of titanium.

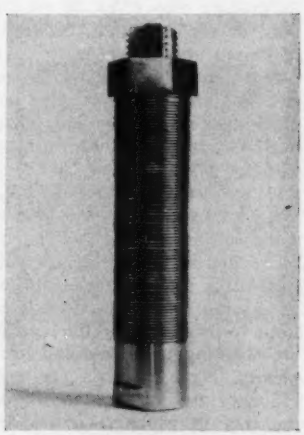


Fig. 14. Titanium pack for filtering sodium hypochlorite. (Photo courtesy of Metafiltration Co.)

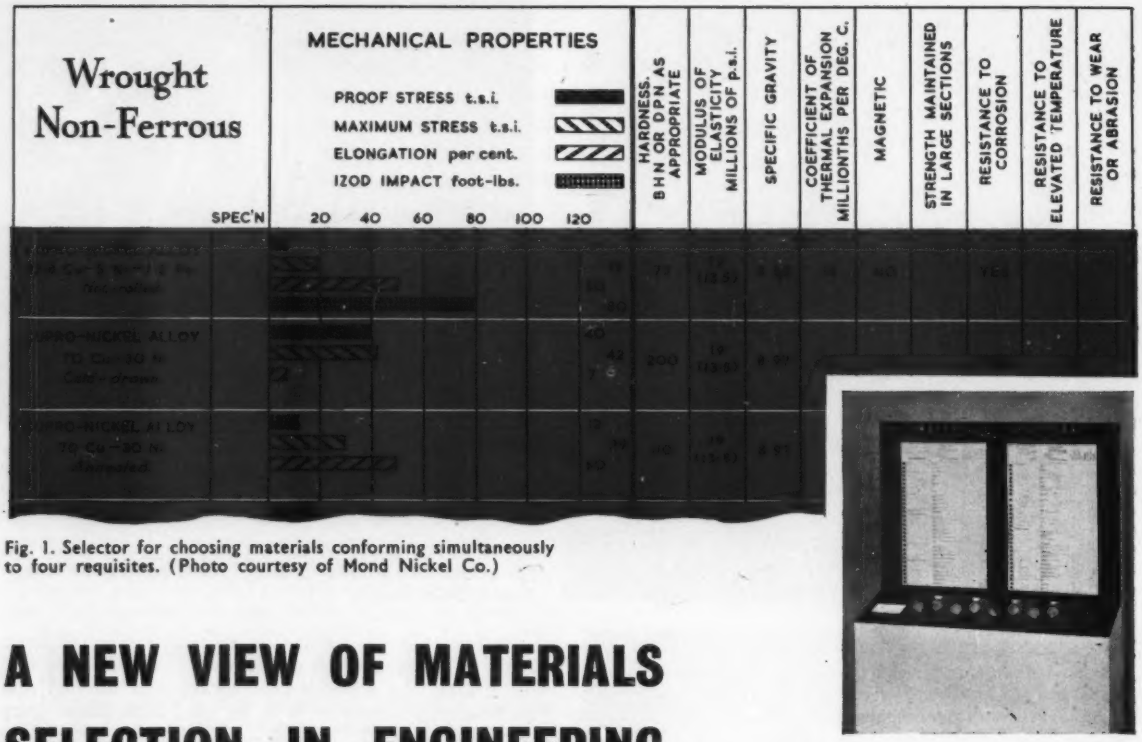


Fig. 1. Selector for choosing materials conforming simultaneously to four requisites. (Photo courtesy of Mond Nickel Co.)

A NEW VIEW OF MATERIALS SELECTION IN ENGINEERING

An examination of the problem of materials selection and of the need for a new subject in selection for design with its specialist knowledge and techniques

By A. J. KENNEDY, Ph.D., A.M.I.E.E., F.Inst.P.*

THE development of materials technology is influenced and guided by two main spheres of activity: engineering design and demand on the one hand and advances in materials science and production on the other. Each, in turn, exerts its influence, and progress in modern technology may often be reduced to a process of adaptation, or reconciliation, between these twin considerations of design and materials.

In comparatively recent times, say the last twenty years or so, quite new difficulties have arisen in this field. In part, these result from the greater variety of the materials available, but more profound complications than this exist which, on analysis, reveal the inadequacy of our present selection methods. We have not, as yet, begun to deal with this as a subject in its own right, and sooner or later some serious attempt will have to be made to reorganise our materials information, and the way we use this information, into more fruitful and flexible forms. We may be assured that the present selection methods cannot continue to serve us in technological situations where materials are working under limited life conditions of great complexity. New methods are needed which will, in turn, influence the very nature of our testing procedures and the way in which data are derived from the results of such tests. While certain hopeful developments have been made in recent years, it is true to say that many difficulties remain which appear at the present time to prevent altogether the establishment of a selection procedure capable of handling the more complicated conditions. These difficulties will not be surmounted unless the subject is treated as an important one, worthy of specialist research and investment. Granted this, it may well be possible to make a real advance in this field within the next five to ten years. Certainly some such attempt will have to be made before long.

* *Professor of Materials and Metallurgy, College of Aeronautics, Cranfield.*

The Nature of the Selection Problem

If only one design consideration enters into the selection of the material for a particular component (as, for example, strength at a fixed temperature), then the logical process of selection is trivial, even though, if a large number of possible materials exist, the collection of data may be laborious.

Much of engineering design in the past has involved little more than this. As soon as a second consideration arises (such as corrosion resistance, or ductility, or lightness) then the process of selection involves judgment, in that an appropriate balance between the different properties has to be achieved. When specifications can be drawn up for particular applications in which the minimum requirements, for each of the quantities involved, can be laid down, then the process of selection is still (logically)

trivial, even though the amount of testing required may be considerable and expensive. Given the data, selection methods may be mechanised, at least in part, provided the conditions imposed are simple ones. An example of such a system is that constructed for demonstration purposes by the Mond Nickel Co. In this equipment, the optimum material is indicated automatically when the conditions are imposed by the throwing of the relevant switches. The extension of such a selector to a wider range of materials and conditions would obviously be helpful, but it must be emphasised that such a selector does no more than (effectively) consult tables of data. Its response is, in fact, built-in by its designer in the light of his study of such tables. This needs to be underlined, because future developments may well be of a quite different character, as will be indicated later.

It will be evident that selection in this simple form depends upon the ability to define certain test parameters (creep life at a given stress and temperature, for example) and to set an acceptable minimum for such parameters. From the design point of view, this may not always be possible and may in any case be inaccurate. If the machine in question is being run discontinuously, under cyclic conditions of temperature and stress for example, then how can the designer represent his requirements in a form suitable for material selection? Again, much of design is based upon the result of uniaxial stressing, whereas the important practical cases usually involve biaxial, or even triaxial stress systems.

The fact is that at present this kind of difficulty has not been surmounted. Usually, the apparently worst case is designed for, but unfortunately the errors may be large, and the results uneconomical. Indeed, it may not be at all apparent, without more detailed study, just what the worst case is.

The first requirement in advancing the subject is the establishment of the right parameters which may be taken to represent the properties of the material, and in terms of which prediction is at least theoretically possible. This in itself is a quite special field of study, and the amount of research involved is prodigious. Taking creep alone as an example, the number of constants required to specify the creep of a given material over ranges of (fixed) stress and (fixed) temperature is not small. Opinions differ, but few would propose a number less than six, and many more may be required. But even this kind of description is insufficient in itself, because the creep may be affected by other processes such as fatigue, and we therefore have to introduce the effects of such interaction into the design considerations. It is also insufficient in itself, because the parameters must be of such a kind that they are applicable not merely to fixed conditions of stress and temperature, but to the general case. The way in which the empirical behaviour is expressed (in mathematical terms) clearly determines the nature of these parameters, and the working out of the most significant set would appear, in the first place, to be a matter for physics and metallurgy, because the best hope for the evolution of a sensible and representative scheme seems to be that based upon parameters which express the magnitude of the basic physical processes. It may well be that this procedure will prove, even so, too complicated in development, and approximations may certainly be necessary, but to start from an apparently simpler empiricism may very well prove to be a worse course when the more complex cases come to be handled. In other words, attempts to express the history-dependent behaviour of materials must be based upon a proper appraisal of the constituent processes if the complicated technological cases are to be reduced to reasonable proportions.

The Nature of the Selection Process

The ideal selective process may be looked upon as one in which the fully-descriptive set of parameters for a material is set up on a machine (or computer, as it may be called), the required user-conditions then being imposed upon it, and a result derived indicative of the behaviour. Each of these stages is difficult. The right kind of parameters may very well be different from those which conventional tests yield, and it may be expected that a closer examination of the problem will in turn transform the nature of some, at least, of our present test procedures. As an example, the question of creep and fatigue, mentioned above, makes it necessary to establish the influence of each on the other, and combined testing may well replace much of the separate creep and fatigue data-collection which goes on at the present time. Where the quantity *time* enters into the design scheme, it is obviously desirable that the ideal computer we have postulated should work in a much compressed time-scale. This is certainly readily achieved with computers, or computer type units generally, the immediate difficulty being rather how the parameters in question may be set up on the machine. Again, this is a specialist field of study, but some progress has been made in producing such an electrical analogue computer for the more simple creep problems, and there seems to be no great difficulty, in theory at least, in its extension to a wider class of conditions. Whether the type of electrical model developed in this context is capable of simulating the characteristics of other properties, such as fatigue, is another matter.

The setting-up of the user conditions on the computer, or simulator, raises difficulties of much the same kind. Actual possibilities could only be discussed in detailed

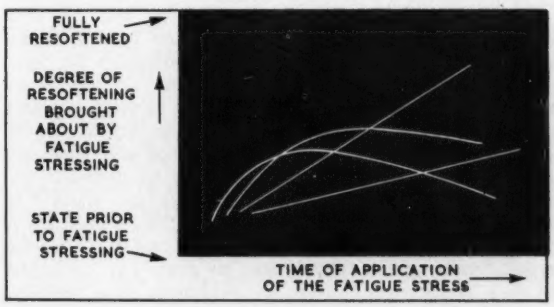

FULLY RESOFTENED
DEGREE OF RESOFTENING BROUGHT ABOUT BY FATIGUE STRESSING
STATE PRIOR TO FATIGUE STRESSING
TIME OF APPLICATION OF THE FATIGUE STRESS

Fig. 2 (*left*). Effect of fatigue stress on metals earlier subjected to creep. For longer times of application, low fatigue stresses dissipate the work-hardening caused by the previous creep much more than high-fatigue stresses; but the low stresses produce little or no fatigue damage. Optimum balance between creep and fatigue design requirements must therefore be found.

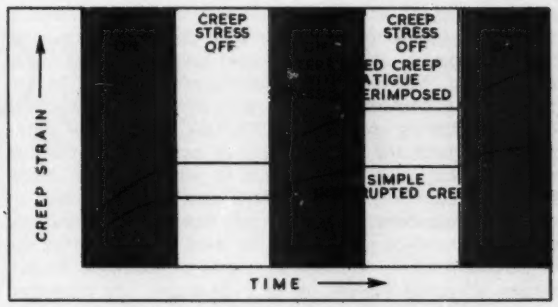


Fig. 3. Imposition of a fatigue stress during a creep test usually accelerates creep and increases softening during the off-load periods, except when the fatigue stress is very high.

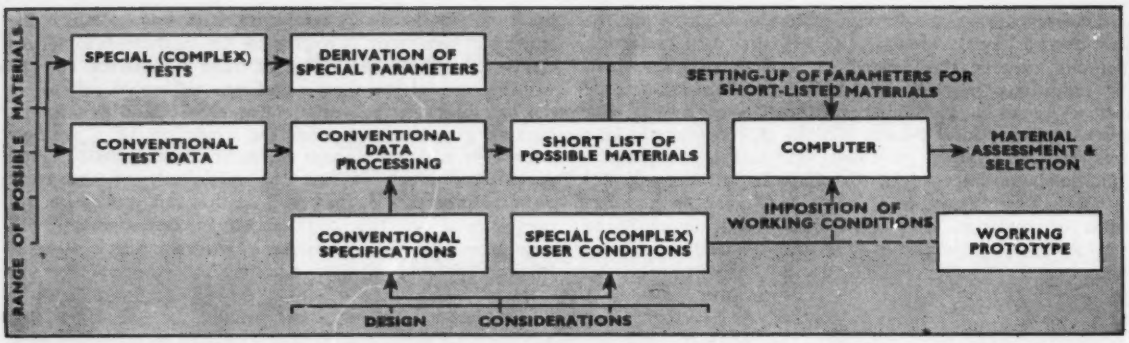


Fig. 4. Stages in a possible selection process.

terms which would be beyond the scope of the present article. The basic problem is obviously one of correct simulation, in terms of the electrical analogue; once this is achieved, then there is no reason why the engineering machine under design should not be coupled in, through standard transducers, to the computer, and the user conditions may then be imposed directly, but in real time and not in a shortened time-scale. This kind of development seems to be a most fruitful possibility.

It may be observed here that the simulator of this ideal system is a computer in the real sense of the word and not merely a data-consulting device. It is, in fact, simulating the complex behaviour of a selected material and providing answers which cannot, in the light of present knowledge, be obtained by any other method, because of the difficulties of the analysis and the magnitude of the approximations involved.

Requirements of a Comprehensive Process

We may now review what is required in a comprehensive selection scheme. In the first place, information is required on all the possible alloys and other materials under production. This information we may assume to be in two forms—conventional and unconventional. The conventional data, which we may take to be all that used by design at the present time, must be stored in a form suitable for rapid consultation: in other words, the methods of data-processing need to be applied to the problem. It is surprising that so little, to date, has been done in this direction.

The more subtle and difficult considerations, are, however, those which relate to what we may call unconventional data. They arise, as has been said, because the standard data, as obtained in the past, are inadequate as a basis for the proper assessment of material behaviour under more extreme conditions. Nor can we merely extend the amount of such conventional data, while retaining their basic form, in the hope that greater information, and the better organisation and accessibility of such information, will meet the requirements. It would be unrealistic to contemplate the exhaustive and extensive degree of testing required for the full appraisal of every material, under the great variety of possible programmes to which they may be subjected in practice. It is, therefore, a matter of some concern that a description of material behaviour, in terms of representative indices, should be evolved which may be used as a basis for the construction of an economical system of selection. Such a system may still involve, in its final stages, the operation of individual judgment, but at least it will reduce the questions to ones which are more easily subject to such judgment and eliminate much of the present guesswork.

It is obviously very necessary that such a scheme should be allied to a new set of tests which represent more adequately the important features of the technological operating conditions. The development of such tests, and their establishment in the repertoire, therefore forms an important field of study in itself. Having been conditioned by established practice to think in terms of tests which, by their very design, isolate particular properties and measure these under fixed and controlled conditions, it is difficult to accept with any readiness innovations based on a quite different philosophy. We cannot consider the behaviour of materials under complex conditions to be simply the sum of their responses to the individual conditions applied in isolation. This we know perfectly well, from such examples as stress-corrosion or fatigue-accelerated relaxation, and on a small scale these effects are recognised by adapting tests accordingly. But the old philosophy is deeply entrenched, and there is no great readiness to embark upon the evolution of new test procedures.

There are, however, certain additional complications which have not so far figured in the arguments. Materials are useful only as components in a final assembly. The fabrication of these components and the nature of the assembly operations, may impose quite special restrictions in such matters as formability or heat treatment. If the field already discussed is widened even further by introducing sequential operations into the conditions it is unlikely that any scheme would stand the strain. The most sensible view to take seems to be to restrict the assessment to material behaviour under the required user conditions (the word "material" here naturally embraces such material-production variables as those of different heat treatment or mechanical working) so that some classification of their quality may be derived as a basis for final judgment. In the course of this judgment, special industrial or economic factors may arise to influence the final decision, but these will always exist and cannot be excluded from the scheme of things.

To summarise the situation briefly, we may say that there is a pressing need for the creation of a specialist study concerned with the selection of materials for technological applications. The development of this study entails research into a variety of related subjects, physical, metallurgical, logical, computational and organisational, and it is to be hoped that those concerned with materials in technology may feel it worth while to promote and encourage efforts along these lines. We can hardly be confident at the present time that the best use is being made of the materials available to us, and the situation grows rapidly more difficult year by year. The institution of such researches, and the establishment of a selection system, will not be cheap, but in the long-term its results could be far-reaching, not merely in providing rapid and effective answers to specific design questions, but in positively eliminating a vast amount of the expensive and time-consuming testing which takes up so much of our industrial resources at the present time.

SELECTION OF FRACTIONAL HORSEPOWER ELECTRIC MOTORS

Fhp motors are frequently required by engineering designers who may not be familiar with their characteristics. This review describes the most popular types of motor available. Factors affecting the actual selection of motors will be discussed in a second article in the next issue.

by H. J. CADOUX, M.A. (Oxon), A.M.I.E.E.*

WITH the rapid growth of motorisation in mechanical equipment, it is important that engineering designers should understand the characteristics of the types of f.h.p. motors that are available.

Owing to the very large variety of motors to be considered and the impossibility of dealing comprehensively with them all, it has been decided to confine this article to those types of machine generally available from stock and exclude those which have to be individually developed. This will exclude such motors as hysteresis, synchronous reluctance and those types incorporating permanent magnets. Servo-motors and "torque" motors for highly specialised control operations will also be excluded.

The types of motor to be described can be seen from Figure 1. Of the two broad divisions, a.c. and d.c., the larger grouping is of a.c. motors and the virtual extinction of d.c. supplies in the last few decades accounts for this. There has, however, been a certain revival of interest in d.c. machinery in recent years, partly owing to the suitability of these motors for variable speed applications.

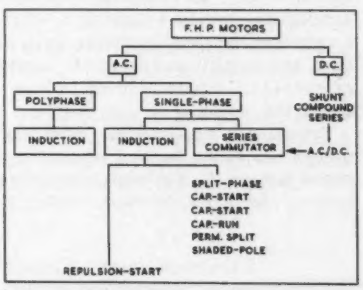


Fig. 1. Types of f.h.p. motor dealt with in this article.

Main Types of Motor

Split - phase (Resistance Split-phase Start, Induction-run) Motor

Figure 2 shows diagrammatically the arrangement of the winding and a speed-torque curve for this type of motor. Split-phase motors are the common workhorse for ratings between $\frac{1}{8}$ and $\frac{1}{2}$ h.p. They are cheap, robust and their performance suits the vast majority of applications. A feature of the split-phase (see also capacitor-start) type is the mechanically-operated switch which open-circuits the start winding at a predetermined speed, usually about 80 per cent of the synchronous value. The motors are generally capable of taking considerable overloads for short periods and, as can be seen from the speed/torque curve, the maximum torque that the motor can produce is usually somewhat over 200 per cent of the full load value. Naturally, this torque rating should not be approached in service, but it gives an idea of the operating characteristics of the motor to a point considerably above the full load value.

As the start winding heats very rapidly, it is essential that the circuit should operate within approximately one second of switching on and, as starting torque is generally low, the

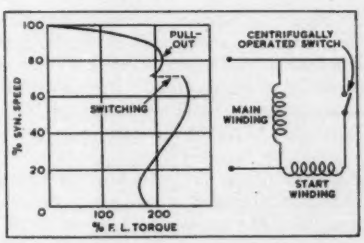


Fig. 2. Split-phase (resistance split - phase start, induction-run) motor.

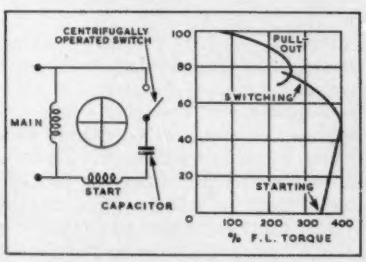


Fig. 3. Capacitor-start (capacitor split-phase start, induction-run) motor.

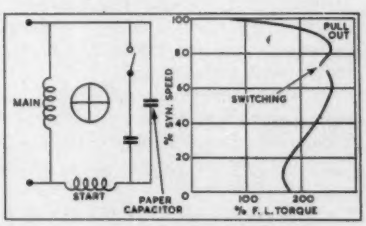


Fig. 4. Capacitor-start, capacitor-run motor.

* *Manager of research and development laboratory, Ranco Ltd., and until recently chief electrical designer for a major f.h.p. motor manufacturer.*

motor is not considered suitable for use with loads of high inertia. An average value for starting torque is about 150 per cent full load torque (f.l.t.), though higher values are met in practice on some machines. Split-phase machines should generally not be used on applications which demand more than, say, 75 per cent f.l.t. at starting where the supply voltage is liable to vary and local line voltage drop due to the high current of starting may occur.

Motors can be made with values up to and even exceeding 250 per cent f.l.t., but it must be realised that these torques are only obtained at the expense of a very heavy starting current. For this reason it is usual to find the listed starting torques of motors dropping from, say, a value of approximately 200 per cent at $\frac{1}{4}$ h.p. to perhaps only 120 per cent at $\frac{1}{2}$ h.p. This does not mean that high-torque motors on $\frac{1}{2}$ h.p. cannot be made, but it is in the user's interest not to demand of the order of 250 per cent on this rating as, not only may much of it be lost at the moment of switching on due to voltage drop, but other users may be annoyed by severe momentary voltage fluctuation in the local circuitry. Starting currents met in practice are of the order of 700-800 per cent f.l. for normal-torque motors, but up to 1,000 per cent f.l. on motors with high torque.

Various alternatives to centrifugally-operated switches to open-circuit the start winding after the motor has gained speed can be employed. The most popular of these depends on the change of current in the main winding during the accelerating period operating a small magnetic relay with a switch in the starting circuit. Such magnetic devices, however, are usually met on small "conventional" type motors of, say, 1/100 h.p. to 1/10 h.p., where size precludes a switch inside the motor.

Specialised applications exist for which high-torque motors are called for and where the disadvantages of split-phase motors do not apply. In general, for a high starting torque, the capacitor-start motor should be considered.

Capacitor-start (Capacitor Split-phase Start Induction-run) Motor

Figure 3 indicates the connections and characteristics of this type of motor, and it will be seen that the diagram is the same as Figure 2, except that a capacitor has been inserted in that branch of the circuit which includes the start winding, and that the performance curve has been altered, not by an increase in torque on the run condition, but by an increase in starting torque and acceleration. The addition of the capacitor increases torque and reduces starting current. As it is necessary, for the best results, for the number of start winding turns to be increased, compared to a split-phase machine (and thereby slightly increase the weight of copper used), the increased cost of a capacitor motor is not solely caused by the capacitor. By obtaining the right number of turns, however, the designer can control the characteristics over a wide range to cater for low starting currents or high starting torque. If not otherwise specified, a value of 300-400 per cent f.l.t. is usually supplied, but if a lower torque figure can be tolerated, the customer should mention the fact, as some economies can be obtained by using a capacitor having a lower value.

It is usual to employ electrolytic capacitors for this duty. These are customarily short-time rated and it is recommended that, for normal ambient temperatures in this country, the total time they are switched on should not exceed one minute per hour (i.e., 60 one-second starts, 30 two-second starts, etc.).

The wise designer will always try to arrange for the capacitor voltage to be somewhat less than the rated value. This gives a factor of safety. During the accelerating period, the capacitor voltage tends to drop slightly at relatively low speeds, but rises very sharply from a slip of about 0·3 onwards until (if the starting switch fails to open-circuit the start-winding circuit) the capacitor voltage might well be nearly twice the stated maximum at light running speed.

Irrespective of the value of starting torque produced, between, say, 250-400 per cent f.l.t., the starting current will lie within 350-450 per cent of the full load value. It is therefore possible, for a given value of starting torque, roughly to halve the split-phase motor current by adopting the use of a capacitor motor. A further advantage of the capacitor motor over the split-phase type is that the rate of temperature rise of the starter winding is much less, so that it can be left on the line stalled for approximately four times as long. This means that the limiting factor tends to become not the motor winding but the capacitor.

The capacitor motor may be considered for its high starting torque as suitable for high inertia loads and, owing to its low starting-current/starting-torque ratio, has virtually superseded the repulsion-start induction motor, although this latter machine usually takes even less starting current.

For a machine with slightly higher efficiency and quieter running, the capacitor-start, capacitor-run motor should be considered.

Capacitor-start, Capacitor-run Motor

Figure 4 indicates the connection diagram and it will be seen that a further capacitor is in evidence which remains in circuit even when the centrifugal switch is open. Little change, if any, will be observed in the torque characteristics, though usually a somewhat higher efficiency will be recorded. This extra capacitor will be of the impregnated-paper type, and generally rated at approximately twice the supply voltage. It is always of a much smaller capacity and higher impedance than the electrolytic starting capacitor. The characteristics of this type of motor conform closely to those of the capacitor-start type. It is of interest where a machine of high-starting torque with quieter running, lower full-load current and higher efficiency is required. It is,

Fig. 5. TYPES OF ENCLOSURE FOR F.H.P. MOTORS—
(a) Drip-proof.
(Photo courtesy of S.E.M. Ltd.)
(b) Totally-enclosed.
(Photo courtesy of Newman Industries Ltd.)
(c) Totally - enclosed, cooled.
(Photo: Crompton Parkinson

however, a more expensive motor, as the extra capacitor is a relatively costly component.

Permanent-split Capacitor (Capacitor-start and Run Motor

In Figure 7 it is seen that the centrifugal switch and electrolytic capacitor have been eliminated, but the paper capacitor is retained permanently in circuit during all phases of the motor's operation. The performance graph shows that a great deal of starting torque has been lost, but the accelerating and running graph is now a continuous one and there are no switching discontinuities. Starting torque is reduced to roughly 50 per cent of the full load value and the speed at full load has also been somewhat reduced. These characteristics vary, but the graph shown refers particularly to what can be offered for fan duty, where a maximum torque is in the region of 150 per cent f.l.t. Because of the high impedance of the condenser relative to the start winding, the current density in that winding is very low at all times and therefore acceleration can be very prolonged. Although a disadvantage for many applications, its lower starting torque is well suited to those requiring a smooth acceleration from a standstill and quiet running. The motor can be plug-reversed while running and does not need to come to a standstill for this to be done. Certain combinations of winding and capacitor create a characteristic, however, whereby even with plug-reversal, the motor will continue to run in the same direction. If plug-reversal is required for such a motor therefore, the motor manufacturer should be informed.

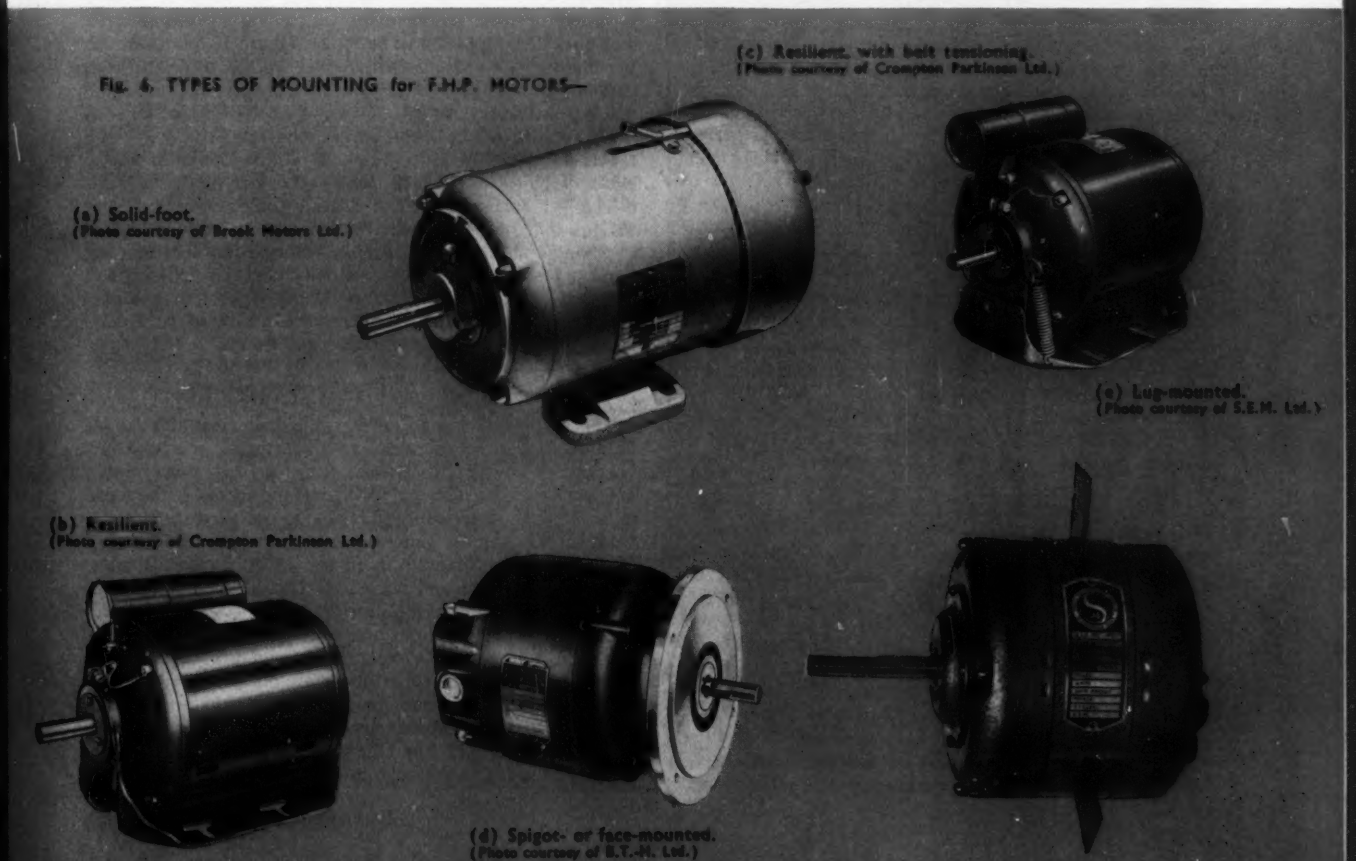
Starting currents are relatively low, of the order of 400 per cent f.l. current. As for the previous machine described, the paper capacitor provides some power-factor correcting action under load conditions so that full-load current is low compared to other motors of the same rating and characteristics, these being generally from 1/40 to ¼ h.p.

Shaded-pole Motor

This motor operates on different principles and is cheaper but less elegant in operation. As will be seen from Figure 8, the torque performance is almost exactly as the permanent split-type capacitor motor. Starting torque is about the same and, for a similar type of duty, e.g., a fan motor, maximum torque would also be of the order of 150 per cent f.l.t. Other applications are few. The connection diagram does not indicate so exactly the internal arrangement as the previous diagrams, but serves to show that there are two windings as in the previous types, the second being isolated from the main circuit. Not shown, however, is that the short-circuited turns link with a small proportion on the flux of the main winding, and so produce, by a phase displacement, a rotational field similar to the other machines, causing the rotor to revolve. Though one of the commonest types of motor, the principle of operation and analysis of design are more complex than anything so far considered. Only comparatively recently have attempts been made to analyse their performance and design and improve their efficiency. However well shaded-pole motors are made, they are inherently incapable of the overall performance of other induction motors. Their use is therefore restricted to applications where inefficiency does not matter. One important advantage they have is that, although full-load current is high compared to other types, with increasing load it tends to remain roughly constant. Even when the motor is fully stalled the current will be little more than 150 per cent of the full-load value. Not so quiet in operation as other types, recent efforts made to remedy this defect have met with considerable success.

Cheap and virtually indestructible, it is a popular motor where servicing is difficult. The variable speed characteristics of both shaded-pole and permanent split-capacitor motors render them particularly suitable for fan application.

Fig. 6. TYPES OF MOUNTING for F.H.P. MOTORS—


(a) Solid-foot.
(Photo courtesy of Brook Motors Ltd.)
(c) Resilient, with belt tensioning.
(Photo courtesy of Crompton Parkinson Ltd.)
(e) Lug-mounted.
(Photo courtesy of S.E.M. Ltd.)
(b) Resilient.
(Photo courtesy of Crompton Parkinson Ltd.)
(d) Spigot- or face-mounted.
(Photo courtesy of B.T.-H. Ltd.)

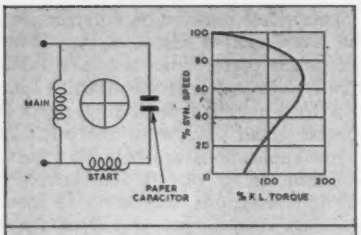


Fig. 7. Permanent-split capacitor (capacitor start and run) motor.

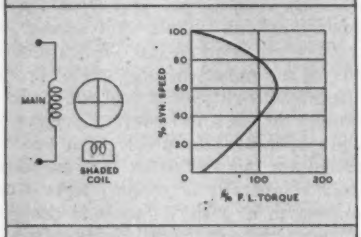


Fig. 8. Shaded-pole motor.

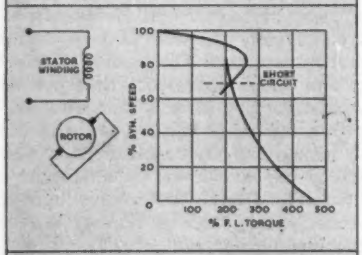


Fig. 9. Repulsion-start (induction - run) motor.

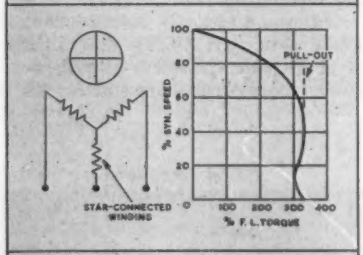


Fig. 10. Polyphase motor.

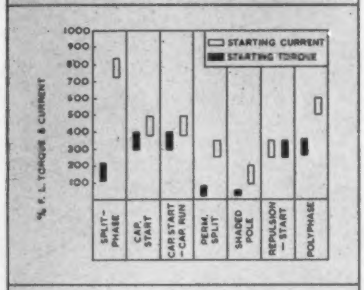


Fig. 11. Variations in starting torque and current for the motors discussed.

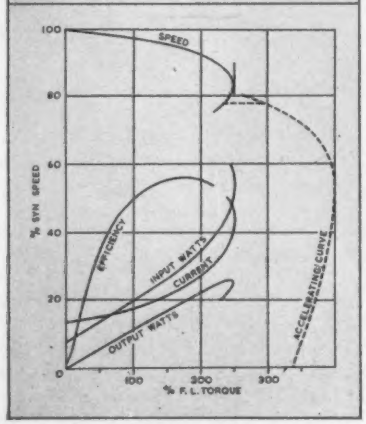


Fig. 12. Performance curves for a ¼-h.p. capacitor motor.

Repulsion-start (Induction-run) Motor

This motor is strikingly different in both the principle of starting it uses and its appearance. All the motors so far described normally use rotors with die-cast aluminium or copper conductors. Although this motor resembles at a casual glance a d.c. machine in that it has a wound rotor with commutator and brushes, closer inspection reveals that the stator winding is quite different and that the brush system is isolated from the external circuit.

Figure 9 shows the arrangement of connections and the speed/torque performance. While at rest and accelerating the opposing brushes are directly connected. They are set at such an angle that there is a net torque in one direction causing the machine to revolve. At a predetermined speed a conducting ring automatically short-circuits all the commutator segments (c.f., action of centrifugally-operated switch) and the motor then behaves as a wound-rotor induction motor.

Though still manufactured, these motors are naturally costly and have lost their popularity. Their high starting-torque, low starting current and avoidance of an electrolytic capacitor, however, make them attractive for some uses.

Polyphase Motor

Usually designed for operation from a three-phase supply, but occasionally also for a two-phase supply, the polyphase f.h.p. induction motor has a characteristic essentially similar to the larger version in the integral horse-power range, except that the rotor is of relatively high resistance. This is not universally true, as certain manufacturers do make polyphase motors with specially designed laminations; generally, however, with a predominance in production of single-phase ratings, adoption of the same punchings and rotor casting tools results automatically in a machine with high rotor-resistance characteristics. The connection diagram shown in Figure 10 is a common one, the choice of connections shown being known as the star connection. Most fractional machines between, say, ¼ and 1 h.p. are supplied with a terminal or lead arrangement which will enable either a star or delta connection to be made. Figure 10 demonstrates the high-torque characteristic and it will be seen that both pull-out and starting torque are of approximately the same value, somewhat over 300 per cent f.l.t. It will also be seen that, because of the speed torque characteristics, full-load speed is lower than on single-phase motors of similar rating. With a high-torque high-resistance rotor polyphase machine, a high value of pull-out and starting torque are inherent if the full-load speed is to approximate to the full-load speed of a single-phase machine of the same rating. The starting current of these machines is usually between 550 and 650 per cent of the full-load value. If initial tests with single-phase machines are successful then the equivalent polyphase rating will automatically also be satisfactory.

Universal Motor (for A.C. or D.C. Supply)

This machine is a kind of hybrid, being essentially similar to a plain d.c. series motor in operational principle, yet because of one or two special features in its construction and because the relationship of current vector is the same in both field and armature, it is able to operate satisfactorily from an a.c. supply, generally over quite a wide range of frequencies. The diagram in Figure 13 illustrates the interconnection of field and armature. The speed/torque curve shows the operation of a motor designed for a.c./d.c. operation under both conditions and the two performance curves illustrate how a somewhat better performance can be obtained when the motor is operating on d.c. supply. These small series-commutator machines find their optimum operating point at speeds usually in the order of 6,000 rev./min., although they can be very much higher. They are found most commonly in the range of horse-powers

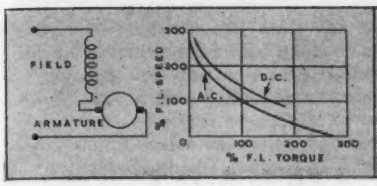


Fig. 13. Universal a.c./d.c. motor.

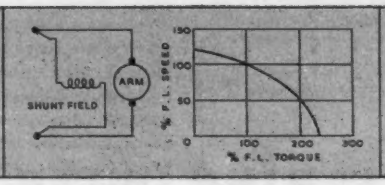


Fig. 14. D.c. motor—shunt connected.

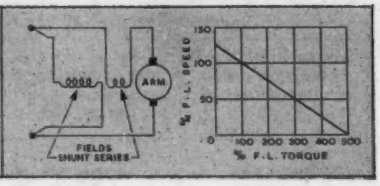


Fig. 15. D.c. motor—compound wound.

from extremely small values up to a maximum of about ½ h.p. Compared to straight d.c. machines, commutation is bad and, for this reason amongst others, it is usual to think of them in terms of intermittent rating. They are of greatest use where relatively large outputs are required for short periods and where cost is an extremely important factor, e.g., cheap mass-produced electrical appliances.

Direct-current Motor

Shunt Connected—Figure 14 illustrates connections and a speed/torque curve. It will be seen that the characteristics of this motor allow a reasonable overload to be taken.

Compound Wound Motor—Connections shown in Figure 15 and torque characteristics illustrate the change which has taken place by the addition of an extra winding in series with the armature, while it will be noted that the regulation is somewhat worse than that of a shunt machine. On the other hand, there is a very great advantage in the absence of sudden speed drop and in the higher starting torque. Machines with this characteristic are generally similar to those in integral horse-power ratings except that, for fractionals, machines having more than two poles are rare, although they can be designed for a wide range of speeds. Additional poles (interpoles), enabling a larger output to be obtained efficiently from a given frame, are usually only encountered in the larger f.h.p. ratings, or for particular applications where there are heavy intermittent overloads.

Series Wound Motors

The characteristic performance of this machine is similar to that for a.c./d.c. series commutator motors. The difference likely to occur if an f.h.p. motor is ordered for d.c. series operation outside the a.c./d.c. sphere is that probably the full-load speed will be well below 6,000 rev./min. D.c. series motors, though, are rarely met in the fractional range.

The production of d.c. motors is now very small, the bulk being a.c. machines, but there has been a considerable resurgence in recent years of the d.c. shunt motor owing to its suitability for controlled variable-speed work when supplied from a rectified a.c. source. Most of the larger motor manufacturers now produce such equipment for d.c. shunt wound machines in the form of a rectifier unit with a variable voltage-control built in. The two main classes obtainable are the grid-controlled thyratron and the metal rectifier plus "variac" voltage control. Both systems are available with and without a form of automatic speed control, which depends on the use of a feed-back circuit compensating for the voltage drop. A very close constant-speed characteristic can be obtained over the working speed range with these forms of apparatus from no-load to full-load.

Motor Enclosures

There is a general, but not universal, tendency for small motors, other than for specialised applications, to be open. For larger machines within the f.h.p. range, drip-proof protection is employed. The three main enclosures normally met are illustrated in Figure 5 and are known as (a) drip-proof (D.P.); (b) totally-enclosed (T.E.); and (c) totally-enclosed fan-cooled (T.E.F.C.).

Naturally, where a small motor is completely enclosed in a cabinet and there is no danger from moisture, dust or accidental touching, there is no purpose in providing any sort of protection. The hazards of transport and handling are not generally considered to warrant a protective shell for these purposes alone.

Most motors in the f.h.p. range are D.P. protected. The precise definition of this can be found in B.S. 170. All that really need be considered, however, is that these motors are so designed as to prevent the ingress of gently falling water in small droplets, the direction of fall being very close to the vertical. Machines of this type dissipate roughly equal proportions of their losses by radiation from the frame and by ventilation through the inlet and outlet ports. A T.E. machine, therefore, will only be able to dissipate about half the loss of the D.P. machine in the same frame. Assuming equal efficiency, a given frame size can accommodate total enclosure at only about half the rating it can deal with in the D.P. enclosure.

Falling somewhere between the D.P. and T.E. machines in cost is the T.E.F.C. motor, which is provided with an additional fan on the motor shaft to force cooling air round the carcase. This enables the same frame size to be employed for D.P. machines, and there is a marked saving in magnetic material. The T.E.F.C. type is therefore often preferable to the full T.E. machine.

Small in-built protection devices for single-phase motors are widely available. In these an element sensitive to temperature variation operates a cut-out in the main supply to the motor. By careful proportioning of the internal motor ambient and the effect of current heating, very efficient protection can be given to motors under almost all conditions of loading. These devices are generally available either for manual or automatic resetting.

The main British Standard specification controlling the electrical performance of f.h.p. motors is B.S. 170 and this has remained unrevised, except for minor alterations, since 1939. The only motors recognised in this standard are those made with Class A insulation, which permits a maximum temperature rise on the windings of 50 deg. C. Apart from some vague indications of starting torque given in Appendix C, there is nothing in this specification on electrical performance to help the engineer seeking to match motor performance with his application, but it is hoped that the revised standard being prepared will remedy it.

In contrast, standard specifications for appliances such as washing machines and refrigerators, in which the motor is very important, are tending to include detailed information on motor performance.

Our own official standards must always be considered in relation to those of other countries, particularly by those manufacturers engaged in export business. Despite efforts to reduce them, serious inconsistencies between our standards and those of other countries sometimes remain. In addition to all relevant British Standards, engineers should have overseas documents such as CEE, SEMKO, KEMA, VDE, CSA, and the NEMA specification which so admirably fills the gaps of omission in other specifications. Although not necessarily equivalents of B.S. 170, and of varying status in their own countries, these constitute an effort to set a satisfactory minimum standard for motor alone or complete equipment.

DESIGNING WITH IMPACT EXTRUDED COMPONENTS

The essential features of the impact extrusion process as applied to non-ferrous metals are examined here from the standpoint of the engineering designer

*By F. HOWARD, A.M.I.Mech.E.

DESPITE the wide range of everyday articles manufactured by impact extrusion, many people in industry are still unaware of some of the important advantages the process offers for obtaining economical quantity production. In addition to the considerable savings in production costs that can be realised with its use, intricate and unusual component designs are possible, and good dimensional accuracy, finish and improved mechanical properties can be obtained.

The operation of impact extrusion, or cold extrusion as it is sometimes called, has now been in use for a considerable number of years. Toothpaste and other collapsible tubes manufactured from soft ductile materials such as lead, tin and aluminium are among the well-known applications of the process. Other applications include a wide variety of radio components and packaging containers.

Continued development of the process, particularly during post-war years, has made it possible to produce parts of increasing complexity from many non-ferrous materials and alloys, thus opening the field for application to various engineering components.

Useful progress has also been made in developing successful techniques for the cold extrusion of steel. These, however, differ in various ways from non-ferrous extrusion techniques and are not included in this article.

Impact extrusion is a process in which a metal slug, contained within a die, is subjected to pressure or impact from a punch in such a way that the metal is forced to flow plastically through the annular space formed by the radial clearance between the punch and die.

The components produced by this process are most frequently in the form of a hollow shell with a cold-forged base and extruded wall; the internal shape and size of the component is controlled by the punch profile and the exterior of the component by the die profile. Sometimes the whole or part of the component may be in the form of a solid rod, the diameter in this case usually being controlled by the die profile.

The two basic methods of producing impact extrusions are usually referred to as backward extrusion and forward extrusion. In backward extrusion, shown schematically in Fig. 1, the metal flows in the opposite direction to that of the punch travel; the extruded component is then usually stripped from the punch by a stationary stripper plate through which the punch passes.

In forward extrusion, shown schematically in Fig. 2, a pre-formed slug of material is extruded forward through the die in the same direction as that of the punch travel.

* *Senior research engineer, Production Engineering Research Association*

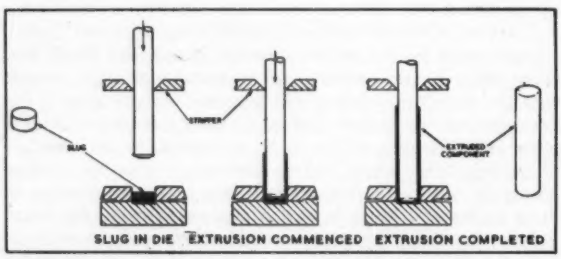


Fig. 1. Diagrammatic layout of a simple backward extrusion.

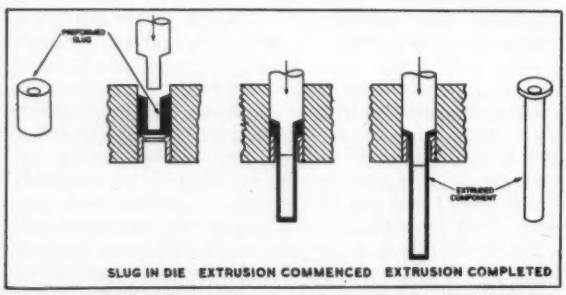


Fig. 2. Diagrammatic layout of a simple forward extrusion using a pre-formed slug.

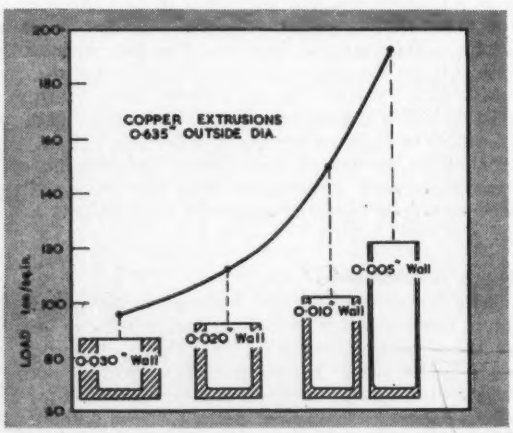


Fig. 3. Relationship between peak force and wall thickness for a copper extrusion.

By using a tapered pilot on the end of the punch, components with tapered side walls can be produced.

The backward and forward methods of impact extrusion are sometimes combined in a single operation, one example being the production of some type of collapsible tubes.

One of the important advantages of backward extrusion is the ease with which different base shapes and thicknesses can be provided on the component. Unlike deep drawing or cupping, the base thickness is entirely independent of the wall size. The operation also lends itself to high-speed production using mechanised slug-feeding arrangements. The main disadvantage is that the overall length of the component is limited by the length of the punch; this cannot be made too slender because of the comparatively high compressive forces exerted on it.

The principal advantage of forward extrusion is that components with a very high length/diameter ratio can be produced in a single operation. Against this must be set the disadvantage that pre-formed slugs are necessary, thus involving an additional press or extrusion operation. Also, particularly with a long component, removal of the extrusion from the punch and die may be difficult and require more elaborate tooling.

Although Figs. 1 and 2 show, for simplicity, the production of plain circular shells, a very wide variety of component shapes is possible using one or other, or a combination of the two, basic extrusion methods. Because of the very wide scope of the process, the temptation often exists to attempt to apply it to a component which was originally designed with other manufacturing operations in mind and is not really suitable for extrusion. In such cases it is sometimes possible to re-design the component to facilitate extrusion, without interfering with the functional requirements of the component.

Ideally, however, components should be designed in the first instance with extrusion in mind.

Materials Suitable for Extrusion

A variety of non-ferrous materials giving a useful range of properties can nowadays be used for the production of impact extrusions. Table 1 lists some of these materials together with the approximate extrusion punch pressures required in backward extrusion for various amounts of deformation. Pressures for forward extrusion are slightly lower than those quoted, but for the purposes of this article can be taken as similar. Apart from magnesium and zinc, the impact extrusion of most other non-ferrous materials is usually carried out at room temperature.

TABLE 1. Pressures required to impact-extrude various non-ferrous materials by the backward process.

Material	Approx. range of extrusion punch pressures required (ton/sq. in.)	Reductions applicable to punch pressures given (%)
Aluminium and aluminium alloys	30 to 100	60 to 98
Copper	80 to 150	60 to 93
Copper alloys	130 to 150	60 to 75
Magnesium and magnesium alloys	20 to 35	85
Zinc	70 to 120	60 to 85
Nickel	130 to 150	60 to 80

TABLE 2. Change in mechanical properties of aluminium after extrusion.

Observation		Material		
		Aluminium 1100[1]	Aluminium 3003[2]	Aluminium 2014[3]
Yield stress (ton/sq. in.)	Before extrusion	2½	3	7½
	After extrusion	9½	15	19½
Tensile stress (ton/sq. in.)	Before extrusion	6½	8	13½
	After extrusion	10	16	23

[1] American Spec. Approx. British Equiv. IC.
[2] " " " " " N3.
[3] " " " " " H4.

The amount of deformation involved during extrusion is usually referred to as the percentage reduction in area (R).

For example, in the case of backward extrusions:

$$R = 100\left(\frac{\text{Original area} - \text{area of extruded wall}}{\text{original area}}\right)$$

With circular backward extrusions, this can be written:

$$R = 100\frac{d^2}{D^2}$$ where d = punch diameter and D = die diameter

With all materials the force required for extrusion increases with increasing reduction, i.e., with decreasing wall thickness. A typical example of the relationship between extrusion force and wall thickness is the curve for copper, shown in Fig. 3.

Since the maximum compressive strength of tool materials currently available for the manufacture of extrusion punches is in the order of 200 ton/sq. in., it is not considered good practice to attempt extrusions under industrial conditions that would involve punch loadings greater than 150 ton/sq. in. The maximum reductions quoted for nickel, copper and copper alloys in Table 1 have accordingly been based on the latter figure.

All materials work-harden during impact extrusion, the extent depending on the amount of deformation involved. With some materials, notably aluminium, a two- or three-fold increase in tensile and yield strengths is possible, at the expense of a loss in ductility. On the occasions when it is possible to use a component in the extruded condition (i.e., without annealing), it should be possible to specify a softer material than would otherwise be used. For example, aluminium extrusions are sometimes used to replace deep-drawn components normally produced from brass.

LEAD AND TIN—These materials were the first to be impact extruded, and offer little resistance to plastic flow. Very high

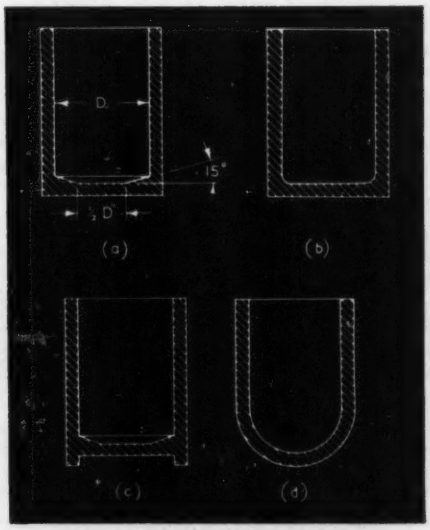


Fig. 4. Four typical base sections.

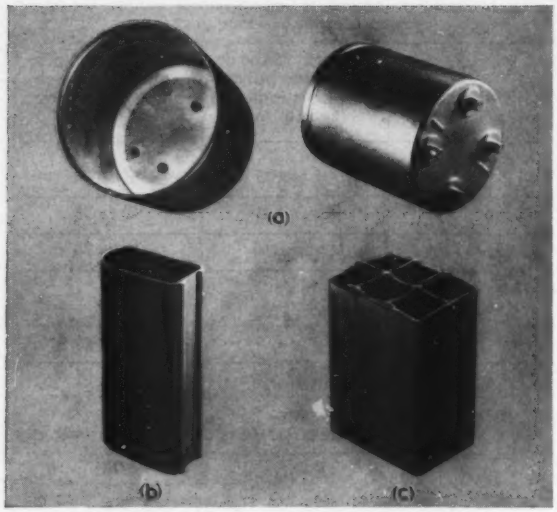


Fig. 5. Examples of typical extrusions. (a) Component with projections on both sides of base. (b) An asymmetrical section. (c) Multi-wall component.

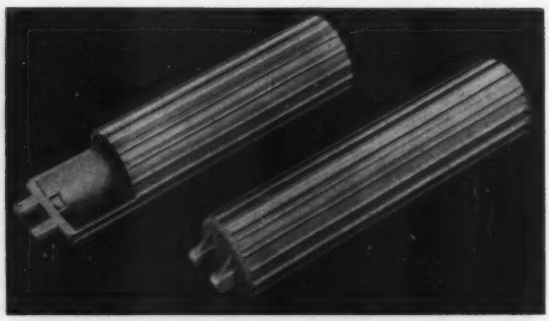


Fig. 6. Component with base projections and fins.

Fig. 7a (left). Component with internal ribs.

Fig. 7b (below). Typical components with external fins. Component shown bottom left of picture was not impact extruded. (Photo courtesy of I.C.I. Ltd.)

TABLE 3. General guide to tolerances for backward extrusion aluminium[3]

Diameter of Extrusion (in.)	Tolerances (in.)		
	O/Dia.	I/Dia.	Base
1	±0·005	±0·006	±0·010
2	±0·007	±0·008	±0·012
3	±0·009	±0·010	±0·015
4	±0·011	±0·012	±0·015
5	±0·014	±0·015	±0·015

reductions are possible and wall thicknesses down to 0·003 in. are stated to have been achieved.[1] Main applications are for collapsible tubes.

ALUMINIUM—More impact extrusions are made from aluminium and its alloys than any other non-ferrous material. The commercially-pure materials extrude the most readily, but little difficulty is experienced with most work-hardenable alloys. Some of the heat-treatable alloys are extrudable, but with more difficulty, and they require greater force.

Table 2 shows the properties of three aluminium materials before and after extrusion. Unfortunately, the reduction is not known. The excellent improvement in yield strength is particularly noteworthy.

Aluminium is used extensively for collapsible tubes and extruded containers for pharmaceutical and other products. It is also coming into use for engineering components, replacing brass and, sometimes, steel parts. Various applications to aircraft parts have been carried out, notably in the U.S.A.

COPPER—Applications of impact extrusion in copper and copper alloys seem very limited. Electrolytic copper extrudes readily, but requires more force than would appear to be necessary, judging from the properties of the material, and it is not advisable to attempt reductions of greater than 93 per cent. Of the various brasses, those with a zinc content of up to 20 per cent will impact-extrude, but the forces involved are higher than for copper and reductions should be restricted to 75 per cent. With 70/30 brass, very high punch loads are required and reductions should be restricted to 60 per cent. Impact extrusion is not satisfactory with 60/40 brass.

If thin-walled components are required, more than one extrusion operation or, alternatively, subsequent drawing and ironing operations may be required. Before attempting a subsequent operation, the extrusion will require an annealing operation to remove the work-hardening and restore the structure.

MAGNESIUM—A fairly recent development, impact extrusion was initially confined to commercially-pure magnesium, but is now being applied to various alloys. Extrusion is usually carried out with slugs heated to 200 deg. C. to 300 deg. C. and sometimes, it is reported, up to 400 deg. C. At these temperatures, the metal extrudes readily with less force than for aluminium and high reductions with wall thicknesses down to 0·006 in. have been reported.[1]

Amongst the interesting properties of magnesium are light weight and excellent rigidity, good electrical and heat conductivity, and corrosion resistance to many organic chemicals, alkaline solutions and oils. The metal does not work-harden greatly during extrusion.

ZINC—Zinc can be impact extruded cold, but sometimes heated slugs are used. In either case, the metal flows readily without requiring excessive punch loads. Very little work-hardening takes place during extrusion.

The main applications appear to be for dry battery

cases and various electrical components.

NICKEL—Loads required for impact extrusion of pure nickel are high and reductions should not exceed 80 per cent. Lubrication troubles may be experienced during extrusion and the slugs may have to be coated with a softer non-ferrous material to prevent galling and material "pick-up" on the tooling.

Design Features for Extrusion

A good idea of the scope of the impact extrusion process can be given by separately considering some of the many design features that are applicable.

WALL THICKNESS—The range of thicknesses possible depends on the component diameter and material.

COMPONENT LENGTH/DIAMETER RATIO—For backward extrusions, this is also dependent on the component material and, to a lesser extent, the degree of reduction involved. In general, the following ratios may be used as a guide:

Lead and tin	6 to 8
Aluminium and aluminium alloys ...	5 to 7
Copper and copper alloys	3 to 5
Magnesium and magnesium alloys ...	5 to 7
Zinc	4 to 6
Nickel	3 to 4

Forward extrusions, which do not require the use of long, slender punches are not subject to the length/diameter limitations quoted above. The main limitations on length are imposed by the press capacity and space to accommodate a completed extrusion. With this type of extrusion, length/diameter ratios of 20 to 30 are not uncommon.

BASE SHAPE—Many variations in this are possible and four typical base sections are shown in Fig. 4. Of these, the design shown at (a) is widely used in the belief that the taper assists metal flow over the end of the punch. Although this is of little practical value, a more valid reason for specifying this base shape is that the additional metal at the bottom of the extrusion lessens the risk of weakness which may sometimes occur with thin flat bases. Of the remaining shapes, the hemispherical end (d) is the most difficult.

Projections or depressions may be provided on both sides of the base, typical examples being those shown in Fig. 5a. The arrangement of these should be as symmetrical as possible to avoid unbalanced loading of the tools. A further example of base projections are the two parts shown in Fig. 6. In this case the projections are heavy, the metal having been forward extruded into the die cavity prior to backward extrusion of the walls taking place.

BASE THICKNESS—This is solely governed by the press setting and is therefore independent of the wall thickness. The base thickness may be varied over wide limits, but should not be smaller than the wall thickness.

COMPONENT SECTION—With both backward and forward extrusion, non-circular as well as circular shapes can be produced (Fig. 5b). External and internal axial ribs or fins are also possible (Fig. 7). Asymmetrical sections are not impossible to produce, but they cause uneven tool loading and may result in poor tool life. If a component with one longitudinal rib is required, it is preferable, for example, to introduce another diametrically-opposite rib, even if this has no functional purpose.

FLANGES—Flanges up to three times the component diameter can be provided at one end of a component when using the forward extrusion process. The flange may be at an angle or square to the extrusion wall, or it may be wedge-shaped. Projections and depressions can be provided on the flange in a similar manner to extrusion bases. The flange thickness should not be smaller than the wall thickness of the component part.

MULTI-DIAMETER PARTS—Parts with two different diameters can be produced by forward and backward extrusion in one operation. The smallest diameter is usually forward extruded. Parts with more than two diameters usually require more than one operation.

MULTI-WALL PARTS—It is sometimes useful to be able to produce a part having multi-walls and a common base. Trimming condensers for radio sets are a typical example, produced by backward extrusion using a punch consisting of different-diameter cylinders assembled together. Another interesting and rather more unusual example of this type of part is shown in Fig. 5c. This is also produced by backward extrusion, the punch being built-up of six segments.

SOLID PARTS—Solid parts such as shafts can be produced by forward operation, several operations sometimes being necessary for multi-diameter components. Sections can be other than circular.

TAPERED PARTS—Production of parts requiring a taper is generally not feasible by impact extrusion alone. An exception is where a hollow part has a tapered section joining two sections of different diameter; in this case, the tapered section would be produced in compression during a combined forward and backward extrusion.

The illustrations and remarks in this section are not intended to represent the complete range of variations possible in extrusion design; they have, in fact, been compiled from a much wider range of successfully extruded components in order to illustrate some of the basic principles involved.

With correctly designed and manufactured tools and efficient lubrication during the operation, impact extrusions can be produced with an excellent surface finish that takes readily to plating and other metal finishing processes. Close tolerances can also be held, though these are very much dependent on the condition of the tooling and of the power press (see Table 3).

An allowance of $\frac{1}{4}$ in. should be made to cover the removal of the irregular edge invariably formed at the top of circular backward extrusions. This allowance should be doubled for extrusions of non-circular section.

Authenticated cost savings resulting from the substitution of impact extrusion operations for more conventional ones are difficult to obtain, probably because, as yet, the application of extrusion to engineering components is still not very widespread.

However, one interesting example where savings are possible is a square-section container. In this case a single-operation extrusion in aluminium makes a satisfactory replacement for a brass pressing, normally produced in four operations with inter-stage annealing. The material saving in this example is only slight, but the operation times are considerably reduced and expensive heat-treatments are wholly eliminated.

The most fruitful field for application of impact extrusion is for the replacement of components normally produced by machining. In one recent example of a small aluminium part, a material saving of 66 per cent was made and the production rate was increased by ten times, thereby resulting in a total annual saving of £5,000.

There is no doubt that, given the right application, impact extrusion is a very successful operation.

ACKNOWLEDGEMENT

The author would like to thank the director and council of the Production Engineering Research Association for permission to publish this article.

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[1] *Materials and Methods*, U.S.A., August, 1955.
[2] *Alcoa Impact Extrusions*, 1948. Aluminium Co. of America.

Winding coils for fractional-horsepower motors. Photo courtesy of G.E.C. Ltd.

ENAMELLED WIRES FOR ELECTRICAL USES

A survey of the many types of enamelled wires now available to the electrical designer

by R. H. BLEWITT, B.Sc.*

IN recent years the field of insulated conductors has been revolutionised by the introduction of many new types of synthetic enamelled wires which offer extremely good mechanical, thermal and electrical properties.

The thickness of the enamelled covering required to give adequate electrical properties is much less than that required for fibrous coverings with the result that a much improved space factor can be obtained, which results in reduced size, improved performance and also a better thermal path for the dissipation of heat from the winding.

Coincident with the development of these synthetic enamels, there has been a parallel development of a very large range of synthetic insulating films, fabrics and impregnating and coating varnishes.

The original concept for the thermal classification of insulating materials was to separate them into four basic types identified by their chemical compositions (i.e., organic and inorganic).

Class "O". 90 deg. C.	Unimpregnated organic materials.
Class "A". 105 deg. C.	Organic materials impregnated with oil or resin.
Class "B". 130 deg C.	Inorganic materials with a binding cement.
Class "C". 180 deg. C.	Inorganic materials without a binder.

On this basis, the enamelled wires were restricted to Class "A", which was acceptable when only oleo-resinous type enamel was available, but did not represent the properties of the newer synthetic materials. The new films, fabrics and varnishes were also restricted to Class "A" temperatures, though their properties justified their use at considerably higher temperatures.

To enable a more realistic approach to be made to the classification of present-day materials, it has been necessary to abandon the chemical composition concept of temperature classification and also to introduce additional temperature gradings.

The new temperature classifications are:

Class "Y" (formerly Class "O")	90 deg. C.
Class "A"	105 deg. C.
Class "E"	120 deg. C.
Class "B"	130 deg. C.
Class "F"	155 deg. C.
Class "H"	180 deg. C.
Class "C"	Above 180 deg. C.

These temperatures correspond to the maximum temperatures within the apparatus that will ensure an economic life.

When considering the use of enamelled wires in electrical apparatus, the thermal properties of the other components in the insulation system must be studied, since the ultimate performance depends on their individual characteristics and on their mutual compatibility. It follows, therefore, that the performance of an enamelled wire depends almost as much on the type of impregnating varnish used as on the enamel itself and that any tests carried out to establish its suitability for any specific application should be carried out on an insulation system rather than on the enamelled wire only.

Assuming, therefore, that an appropriate insulating varnish has been selected and that the other components of

* *Witton Laboratories, The General Electric Co. Ltd.*

the system are compatible with the wire enamel, the thermal performance of the various wire enamels currently available can be summarised as:

Oleo resinous	Class "A"
Polyamide	Class "A"
Polyvinylformal	Class "E"
Epoxy	Class "E"
Polyurethane	Class "E"
Acrylic	Class "B"
Polyester	Class "B" or Class "F"
Silicone	Class "B" or Class "F"
P.T.F.E.	Class "C"

The above are general types only and variations exist within these types and in some cases modifications of one type with another.

The assigned temperature classifications given above apply only to the intrinsic thermal stability of the enamels and may be modified by other properties such as cold flow, heat shock, etc.

OLEO RESINOUS—These are required to meet B.S.S. 156: 1951. They were used for the first group of enamelled wires to be developed and are, in general, inferior in most properties to the later types of enamelled wire. They are, however, still useful for the less arduous duties and where their relatively low price outweighs more technical considerations. The main disadvantages are relatively poor abrasion resistance which makes them unsuitable for use in automatic winding machines and lack of solvent resistance which makes them unsuitable for use with modern impregnating varnishes incorporating solvents of the xylol and butanol types and which also require relatively high curing temperatures.

POLYAMIDE—The so-called "nylon" wire enamels which are now becoming obsolescent. The main disadvantages of this type are poor adhesion of the enamel to the conductor and poor moisture resistance. They have been superseded by the polyvinylformal enamels, over which they offer no significant advantages other than solderability without prior removal of the enamel film.

POLYVINYLFORMAL (P.V.A.)—This group is the most widely used and must meet the requirements of B.S.S. 1844:

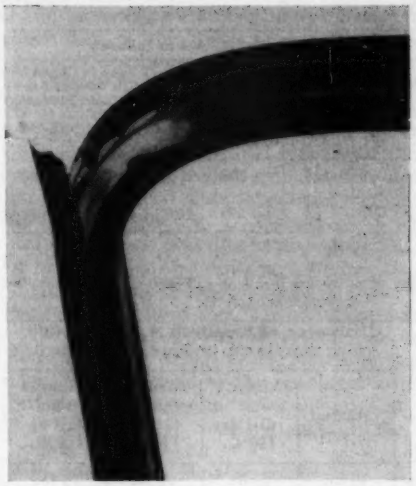


Fig. 1 (above). Typical failure of a polyvinylformal enamelled strip after ageing in insulating oil at 130 deg. C.

Fig. 2 (right). Preparation for the twisted wire test.

1952. They possess excellent mechanical properties, good solvent resistance and good electric strength. Their extremely good thermal shock properties and solvent resistance make them suitable for use with the modern high-curing temperature impregnating varnishes. Some crazing of the enamel does, however, occur and an annealing process (usually done when pre-drying the apparatus) is required before varnish impregnation.

EPOXY—These enamels were developed later than the polyvinylformal types, and, with the exception of slightly better thermal stability, have similar properties. They are consequently not in very general use.

POLYURETHANE—The so-called self-fluxing type which

TABLE 1. Basic properties of different types of wire enamel

Type of Wire Enamel	Abrasion Resistance	Flexibility and Adhesion	Heat Shock	Electric Strength V-Mil.	Solvent Resistance	Moisture Resistance	Resistance to Freon 22	Accelerated Hydrolysis	Varnish Compatibility	Self-fluxing Solderability
Oleo resinous	Poor	Fair	Fair	1,000	Poor	Good	Poor	Poor	Fair	Nil
Polyamide	Fair	Poor	Good	2,000	Fair	Poor	Poor	—	Fair	Fair
Polyvinylformal	Good	Good	Good	2,000	Good	Fair	Fair	Good	Good	Nil
Epoxy	Good	Good	Good	2,500	Very good	Very good	Good	Good	Good	Nil
Polyurethane	Fair	Good	Good	2,500	Good	Very good	Poor	Good	Good	Very good
Acrylic	Good	Good	Good	2,500	Very good	Fair	Very good	Fair	—	Nil
Polyester	Fair	Good	Fair	2,500	Fair	Fair	Poor	Poor	Poor	Nil
Silicone	Fair	Good	Fair	2,000	Fair	Good	Poor	Fair	Poor	Nil
P.T.F.E.	Very poor	Poor	Good	1,500	Very good	Fair	—	—	—	Nil

The comments in the above table represent the properties of the majority of wires of each type, but there are exceptions which may be better or worse than the properties given.

TABLE 2. *Abrasion resistance under oil*

Material	Number of Strokes to Failure					
	Tested at 25°C.	Tested at 130°C.	Aged in Oil for 2 Weeks at 130°C. Tested at 25°C.	Aged in Oil for 2 Weeks at 130°C. Tested at 130°C.	Aged in Oil for 13Weeks at 130°C. Tested at 25°C.	Aged in Oil for 13Weeks at 130°C. Tested at 130°C.
Polyester	>1,000	120	>1,000	100	>1,000	80
Polyvinyl-formal	>1,000	15	40	Nil	10	Nil

TABLE 3. *Flexibility after ageing in oil at 130 deg. C. on rectangular conductors bent on flat*

Material	Diameter of Smallest Mandrel round which sample can be Bent Satisfactorily			
	Unaged	After 1 week in Oil at 130°C.	After 2 Weeks in Oil at 130°C.	After 16 Weeks in Oil at 130°C.
Polyester	$\frac{1}{16}$ in.	$\frac{1}{16}$ in.	$\frac{1}{8}$ in.	$\frac{1}{16}$ in.
Polyvinylformal	$\frac{1}{16}$ in.	1 in.	3 in.	6 in.

TABLE 4. *Self-bonding and plastic flow between enamelled conductors under 500 p s.i.*

Material	Aged for 1 Week in Oil at 130°C.	Aged for 2 Weeks in Oil at 130°C.	Aged for 4 Weeks in Oil at 130°C.	Aged for 16 Weeks in Oil at 130°C.
Polyester	No bond or flow	No bond or flow	No bond or flow	No bond or flow
Polyvinylformal	No bond Slight flow	Slight bond Medium flow	Bonded Heavy flow	Bonded with cut through enamel

TABLE 5. *Heat shock on different makes of polyester enamelled 20 s.w.g wire on a 1 × mandrel*

Material	Elongation		
	Nil	10%	20%
Supplier "A"	Satisfactory 170°C.	Satisfactory 155°C.	Satisfactory 135°C.
Supplier "B"	Satisfactory 145°C.	Satisfactory 140°C.	Satisfactory 135°C.
Supplier "C"	Satisfactory 140°C.	Satisfactory 140°C.	Satisfactory 135°C.
Supplier "D"	Satisfactory 150°C.	Satisfactory 145°C.	Satisfactory 140°C.

permits soldered connections to be made without prior removal of the enamel. This is of great advantage on fine wire coils where removal of an enamel is difficult. The formulation of this enamel can be varied considerably, but, in general, good solderability is obtained at the expense of other properties, with the result that an enamel with adequate self-fluxing properties is generally somewhat inferior to polyvinylformal in its other properties. This fact has tended to confine its use to static applications, particularly radio and television components.

ACRYLIC—One of the more recent wire enamels produced in the U.S.A. on which development and evaluation work are still being carried out. Information so far available suggests that the enamel has better thermal properties than polyvinylformal and, in general, its other properties are at least comparable.

POLYESTER—This is still under development and evaluation. Its superior thermal ageing properties compared with polyvinylformal are now well established. In conjunction with oil-modified phenolic impregnating varnishes it is suitable for Class "B" operation, but with suitable high-temperature varnishes (e.g., modified and straight silicones) it appears likely that Class "F" operation will be satisfactory. In general, however, it is inferior to polyvinylformal in abrasion resistance and in heat shock, particularly when elongated. Care is therefore required when using it on winding machines and to avoid small-radius bends.

The resistance of the enamel to some solvents and varnishes is unsatisfactory and, therefore, tests for compatibility are essential.

SILICONE—Although known as silicone enamels, these are basically other types of enamel modified by a percentage of silicone resin. In properties they are very similar to the polyester types, possessing the same high-temperature thermal ageing properties and similar disadvantages in respect of heat shock and abrasion resistance. They are, in general, only compatible with silicone-based impregnating varnishes.

P.T.F.E.—Polytetrafluoroethylene coatings, though thermally suitable for Class "C" insulation, possess some mechanical properties which prohibit their use for normal applications, but they may be used in very exceptional circumstances. The abrasion resistance of the wire covering is so low that most normal methods of winding are unsatisfactory. In addition, the material suffers from "cold flow" to such a degree that cut-through of the enamel between conductors would occur in any conventional type of winding. To prevent attack of the enamel covering by copper oxides, nickel or silver plating of the copper is usually carried out. Consolidation of the winding by conventional impregnating varnishes is not possible.

Evaluation Tests

Tests carried out on enamelled wires fall broadly into two categories: those which are carried out on specified types of enamelled wires to ensure that they meet the requirements of that particular type, and evaluation tests, which, as has already been said, are usually carried out on

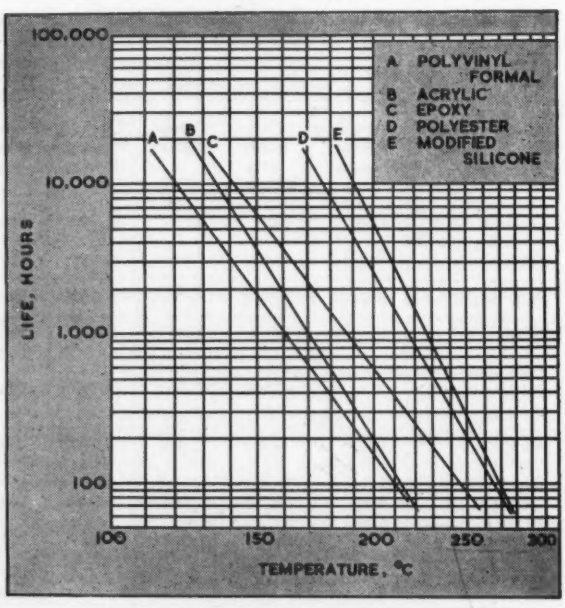


Fig. 3. Thermal life of varnished enamelled wire evaluated by the twisted wire test.

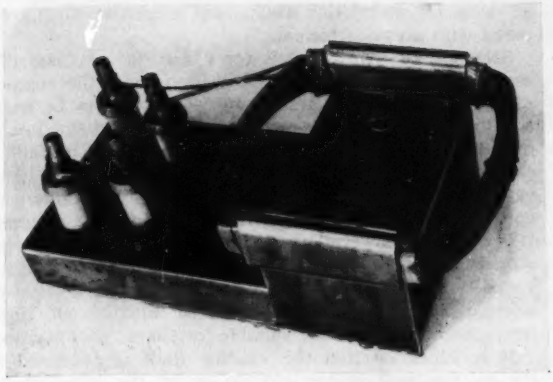


Fig. 4. A motorette used for insulation testing.

composite systems to find whether a system embodying a given combination of wire enamel and impregnant will meet the needs of a particular duty and environment.

In making a critical appraisal of the specific properties of enamelled wires as shown by accelerated evaluation tests, it should be borne in mind that the tests are designed to bring out the ultimate limits of the materials, but it will be understood that, in his appreciation, the machine designer does, by allowing the appropriate margin of safety, enable completely reliable machines to be produced. Evidence of this lies in the many thousands of machines of all types which have given completely satisfactory service over a great number of years and which can be taken to be representative of all types of enamelled wire which are now used in practice.

Type Tests

Most enamelled wires are available in a range of thicknesses of enamel coverings. Normally, four thicknesses are available, designated F (Fine), M (Medium), T (Thick) and X (Extra Thick), though on some types the thicker coverings are unobtainable because of problems in applying the enamel to the wire. The thickness of covering determines the electrical strength and, in addition, the probability of "pin-hole" defects is reduced as the enamel thickness is increased.

The abrasion resistance or hardness of the enamel film is measured by abrading the enamel with a steel pin, which is moved over the surface of the enamel under a fixed load and the number of strokes determined to penetrate the enamel. This test, in addition to being a type test, gives information which is of direct value when considering a particular application and should be correlated, for example, with the performance of the wire on any particular type of winding machine. In those cases where the winding will be subjected to high mechanical and vibrational forces at elevated temperature the abrasion resistance of the enamel should be evaluated at the appropriate elevated temperature.

The value of this type of test can be illustrated by measurement of the abrasion resistance carried out under insulating oil at 20 deg. C. and 130 deg. C. on polyvinylformal and polyester wire enamels, before and after ageing at 130 deg. C. in oil. (See Table 2.)

The marked reduction in the properties of the polyvinylformal enamel is clearly seen, whereas the polyester enamel is not seriously affected.

The tests for "flexibility and adherence" of enamel and "heat ageing" are again normally used as type tests, but they can be readily modified to give information on the suitability of a wire for a particular application.

Table 3 gives a comparison between the performance of polyvinylformal and polyester enamelled strip when tested for "flexibility and adherence" of enamel after ageing in insulating oil at 130 deg. C. Here again the marked superiority of the polyester enamel over the polyvinylformal is clearly demonstrated. (See Figure 1.)

The solvent pressure test specified for polyvinylformal wires is another test which can be modified to obtain specific information. In the specified test four wire crossovers are placed under load in a solvent and the value of insulation resistance between the wires measured after a fixed time interval. Using this basic method but with insulating oil at 130 deg. C. instead of solvent, the relative performance of polyvinylformal strip and polyester strip to self-bonding and flow gave the results in Table 4. In this case bonding and plastic flow rather than insulation resistance has been used as the test criterion.

The "heat shock" test can also be used to give information of specific design value. Normally this test would be carried out by winding the conductor around some specified mandrel, exposing it for one hour at 130 deg C. and then checking for visible cracks on the surface of the enamel. (See Table 5.)

In addition to showing clearly the need for reducing elongation and therefore winding machine tension, and so avoid cracking of the enamel during impregnation, the test clearly shows the different properties to be found in polyester wires of different manufacture. This, of course, applies to some extent in all types of wires, since manufacturers rarely use identical formulations.

Useful information can also be obtained by more specialised tests, such as weight loss on heating, to determine thermal degradation. Softening of the enamel can be investigated by measuring the temperature at which two crossed wires will make electrical contact under specified load and in a fixed time. This is usually referred to as the cut-through temperature.

Any tendency of enamels to hydrolise can be investigated by testing in sealed tubes containing a small quantity of water and maintained at elevated temperature. It is significant that polyester enamels are much inferior to polyvinylformal in this test, but care should be taken when applying the result, since the severe hydrolising conditions used on this test occur rarely in practice.

The value of type tests suitably modified to evaluate specific environmental conditions has been indicated. There are, however, the more complex "composite insulation system" tests, which mainly originated in the U.S.A.

The two most important tests of this type in the evaluation of enamelled wires are: (a) twisted wire test, (b) motorette test.

Twisted Wire Test

The basic test piece consists of two lengths of enamelled wire twisted together to give a fixed number of twists per inch length (Figure 2) and this is then normally varnished with an appropriate impregnating varnish. The test pieces are aged at at least three different temperatures above the anticipated operating temperature. Proof tests at 1 kV. or 2 kV. are carried out between the conductors at the end of each thermal ageing cycle. The length of each cycle between voltage proof tests is so adjusted that failure of the samples occurs in approximately 10 cycles, independent of the ageing temperature.

When analysing the results so obtained, an assumption is made that the rate of thermal degradation follows the Arrhenius Equation for the rate of a chemical reaction. The results are then statistically analysed and plotted with log of life against the reciprocal of absolute temperature in the form of a regression line from which life at any temperature can be deduced.

In practice it is desirable to use one temperature as near to the maximum operating temperature as possible consistent with a reasonably accelerated test. This usually

means selecting a lower test temperature about 250 deg C. above the anticipated maximum operating temperature. If this is not done, significant errors may be incurred in extrapolation caused by inaccuracies in the test and in the assumption that thermal degradation strictly follows the Arrhenius Equation. (See Figure 3.)

The chief advantage of the test is its relative cheapness and simplicity, though it should be realised that several important factors in the life of an insulation system incorporating enamelled wire are ignored.

Motorette Test

This test is more complex than the twisted wire test, but more nearly simulates practical conditions, since, in addition to including the slot insulation and the impregnating varnish, the test piece is also subjected to the effects of moisture and vibration.

Basically, the motorette comprises a set of simple steel pressings which can be assembled to simulate two rotor or stator winding slots. Coils can then be wound into these slots and standard insulating procedure carried out with slot and interphase insulation and normal impregnation. If the coils are wound with two wires in parallel, further information in the form of turn-to-turn breakdowns can also be obtained. (See Figure 4.)

The thermal ageing cycles are similar to those used on the preceding twisted wire test and appropriate proof voltages are applied from coil to earth between coils and between turns. At the end of each thermal ageing cycle which can, if desired, be carried out by current heating, the motorette is subjected to a vibration cycle followed by a high humidity cycle immediately prior to the voltage proof tests.

The test temperatures and cycles are selected in the same way as the previous test and results analysed and interpreted in a similar manner.

The main value of these two evaluation tests, particularly the latter, is to establish the life of an insulating system as related to its individual components and to establish whether these components are compatible with one another, since, as has been mentioned earlier in connection with polyester enamels, some impregnating varnishes are not compatible with enamels and lead to early failure. Similarly, some materials used as slot insulation can adversely affect both the impregnating varnish and the wire enamel and effects of this kind can be conveniently studied in this way.

When deciding on an insulation system the following factors must be considered:

(1) Maximum operating temperature of the apparatus.
(2) Type of winding and whether automatic winding machines will be used.
(3) Minimum radius of bends in the winding and elongation produced by the winding process.
(4) Type of solvent and impregnating medium and, if applicable, its curing temperature.
(5) Mechanical forces and vibration to which the winding will be subject.
(6) Conditions of service and possible hazards such as corrosive vapours.
(7) Whether self-fluxing properties are likely to be advantageous.

Little difficulty will arise if the operating temperature lies within the Class "A" or "E" range as for normal applications; polyvinylformal enamel will be satisfactory. This enamel is compatible with almost all impregnating varnishes and has good heat shock and abrasion properties. If, however, the impregnant is insulating oil, due consideration should be given to the operating temperature in the light of the results already quoted.

Should self-fluxing enamel be considered essential, then the polyurethane type must be used and allowance should be made for its inferior mechanical properties when compared with polyvinylformal.

Selection of wire enamels for Class "B" or Class "F" use require more detailed examination, since the enamels usable at these temperatures are more likely to be sensitive to the choice of impregnating varnish and slot insulation. In general, the appropriate enamels shown in Table I can be used with a conventional oil-modified phenolic varnish for Class "B", whilst for Class "F" modified silicones or other high-temperature varnishes will be required. It is essential, however, that compatibility tests are carried out and the system be evaluated to ensure that the selected varnish has adequate thermal stability. It should be stressed here that not all modified silicones or high-temperature varnishes are suitable for Class "F" operation.

It is important that the winding itself is examined to try to eliminate undue elongation of the wire, small-radius bends and factors which may cause abrasion of the enamel as these types of wires have poorer heat shock and abrasion resistance properties than the polyvinylformal enamels.

High bond strength varnishes are available for Class "B" operation, but Class "F" varnishes have, in general, somewhat lower bond strength than the corresponding lower temperature varnishes.

When considering use in corrosive atmospheres, it should be realised that two properties are required from the impregnant: first, that it is itself unaffected and, secondly, that it provides adequate protection to the enamelled wire.

For temperatures above Class "F" it is unlikely that enamelled wires will be satisfactory and suitably varnished fibrous covering would be used.

In conclusion, it should be said that the choice of the most appropriate insulating system is a matter of careful judgment based upon a consideration of the appraisal of the properties of the material as established by careful testing and operation experience.

Whilst one or other of the types of enamelled wire will be found to be perfectly satisfactory in most cases as a result of the considerable advances which have been made in recent years, occasions may still arise where additional properties are required.

Pending the development of enamelled wires with suitable properties, it is still necessary to use fibrous coverings suitably varnished and the possible advantages of these should not be overlooked in the assessment of insulation systems for special duties.

NEW BOOKS

Mechanics Applied to Engineering, by G. H. Ryder. The general style and clear thinking on the part of the author makes this a valuable book for the first-year degree student, although the Stroud convention of units for distinguishing between force and mass does not permit easy reading. The use of heavy type indicates clearly the coefficients in various expressions, and consistency throughout would have put the text-book well above the general run.

With any text-book it is refreshing to find original and boldly drawn diagrams to illustrate fundamental theories. The contents of this book are rationally arranged; specially recommended are the chapters on linear momentum and impulse, and those dealing with combined linear and angular motion and motion in three dimensions.

The introductory chapter defines basic terms, the following chapters presenting concurrent, parallel, coplanar and non-coplanar forces, motion, work and energy and oscillations, with intermediate chapters 5 and 6 dealing with friction and catenaries. Each chapter contains many worked examples of practical value and ends with a series of set questions together with their answers. R.D.C. (*Cleaver-Hume Press. 21s.*)

NEW DEVELOPMENTS IN HIGH-DENSITY POLYETHYLENE

As well as offering advantages in certain cases over conventional grades, high-density polyethylene is creating for itself entirely new applications in industrial and consumer markets, as this article indicates

by L. A. MUIRHEAD, B.Sc., A.R.I.C.*

THE history of conventional low-density polyethylene is by now well known. During the last war this plastics gained wide acceptance as an insulating material in radar equipment and, as a result of this experience, it has since been possible to broaden its applications to a number of domestic and industrial uses.

Until about eight years ago the only method of preparing polyethylene was by a high-pressure process involving the polymerisation of ethylene gas at about 1,000 atmospheres, yielding a relatively flexible plastics. In 1950, however, new methods of preparing polyethylene were discovered principally by Prof. Ziegler in Germany and the Phillips Petroleum Co. in the U.S.A., in which the use of high pressures

TABLE I.—General properties of high and low density polyethylenes.

	Material Property	High Density Polyethylene	Conventional Polyethylene
Mechanical Properties	Density g/cm³	0·93–0·96	0·92
	Ultimate tensile strength at 25°C. p.s.i.	2800–5000	1500–2000
	% Elongation at break (25°C.)	500–900	200–750
	Modulus of elasticity at 25°C. p.s.i. × 10^5	0·5–1·5	0·19–0·35
	Impact strength at 25°C. ft. lb./in. of notch ¼ in. × ½ in. notch bar	1·0–6·0	>16
	Taber abrasion resistance mg./100 cycles	5–21	23–42
Thermal Properties	Vicat softening point, °C.	120–128	80–90
	Brittleness temperature, °C.	Below –70	–43 to –80
Electrical Properties	Volume resistivity, ohm. cm.	10^{16}–10^{18}	About 10^{19}
	Dielectric constant	2·35	2·3–2·35
	Power factor (10^6 c.p.s.) × 10^{-4}	2·5–10	1–2

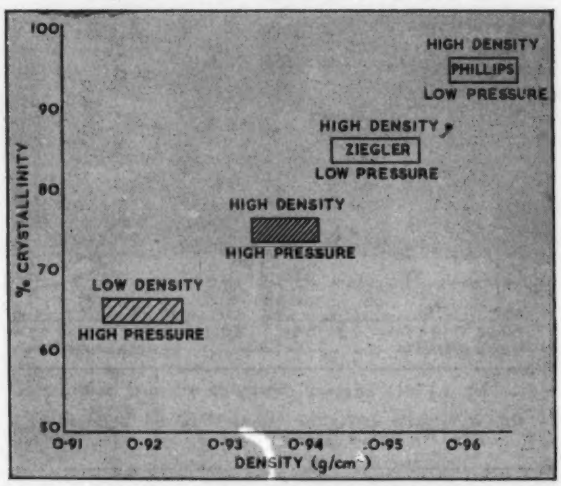


Fig. 1. Schematic representation of main types of polyethylene.

was unnecessary. It was found that the ethylene could be polymerised to a hard polymer by using an organo-metallic compound (in combination with a chosen derivative), or a metal oxide as a catalyst. Although the polymers produced at low pressures are similar in nature to those produced by the earlier high-pressure process, their molecular structures differ.

Infra-red spectroscopic investigations show that the polyethylenes produced by the new catalytic processes have a much lower degree of branching of the molecule. The more linear molecular structure permits a closer packing of the molecules which results in the product having a higher density, greater rigidity and greater tensile strength. Branched (density 0·94) polymers with properties approaching those obtained from the Ziegler and Phillips processes can now be obtained by a modification of the original high-pressure process.

These new polymers, with densities of 0·93-0·96, are usually referred to as high-density polyethylenes to distinguish them from the original types of polymers of density approximately 0·92. They are also sometimes referred to as "linear", "high tensile", Ziegler or Phillips polymers, or by

* *Shell Chemical Co. Ltd.*

Fig. 2. Effect of 128 deg. C. on (left) high-density polyethylene and (right) conventional polyethylene.

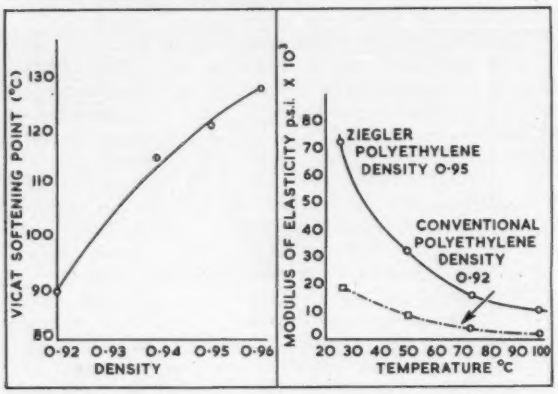


Fig. 3 (left). Effect of density on softening point.

Fig. 4 (right). Effect of temperature on stiffness of polyethylene.

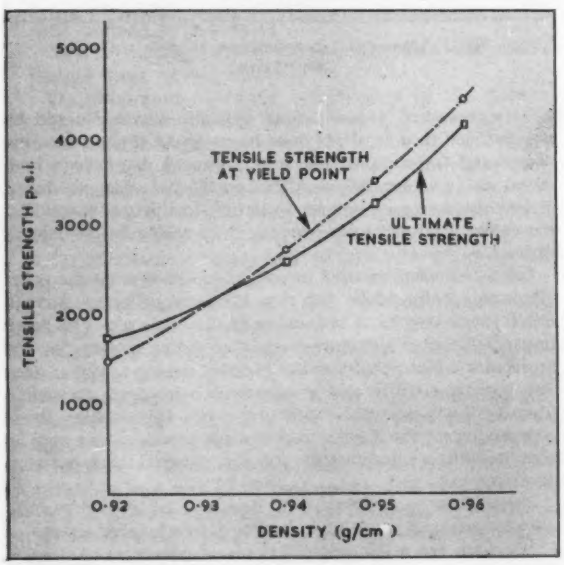


Fig. 5. Relation between density and tensile strength of polyethylene.

their trade names, i.e., Alkathene H.D., Carlona and Rigidex.

The difference in chemical and physical properties of the two types of polyethylene may be directly attributed to their distinctive molecular structures.

The closer the polymer molecules are together, the higher is the crystalline content and, in general, as the crystallinity of a polyethylene is increased significant changes in the physical properties of the polymer are observed. The most important of these (from a practical standpoint) are an increase in tensile strength, an increase in modulus and a significant raising of the softening temperature. Table 1 shows their relative properties. Typical values for crystallinity and related density characteristics for each type of polyethylene are given in Figure 1.

Since the properties of these new types of polyethylene will open fresh potential markets, several manufacturers in Europe have announced plans to produce high-density polyethylene. At present, however, plant capacities are relatively small, and there is consequently a price premium in Europe and the U.S.A. of between 22 and 37 per cent above that for low-density polyethylene.

The high-density polymers can be used in existing thermoplastics machinery. They are processed in a similar fashion to their low-density counterparts, although for injection moulding and extrusion slightly higher processing temperatures are required. A limited range of colours is available from most of the manufacturers for moulding purposes and dry colouring techniques may be used with the natural granules, particularly where pre-plasticiser machines are used. Conventional moulds are in many cases satisfactory, but where maximum performance is required from these new products, modification of moulds may be desirable.

Good Heat Resistance

High-density polyethylenes received much initial attention, as they were one of the first relatively low-priced thermo-plastics which could withstand temperatures of over 100 deg. C. The heat resistance of the polymers may be related to their density, and Figure 2 indicates that under certain conditions some of them can resist temperatures as high as 128 deg. C. (see also Figure 3).

To take advantage of these higher softening points, certain manufacturers have introduced such new products as electric kettles, eggstands, hot water bottles and sterilisable babies' bottles.

Although high-density polyethylene is satisfactory where heat is applied to the plastics for moderate periods only, the use of high-density polyethylene for hot water piping has not yet been developed. Creep problems are liable to occur if continuous operation within the range 70-100 deg.C. is required, and research is now being carried out to eliminate these.

The higher modulus of high-density polyethylenes at both room and elevated temperatures is an important characteristic, and comparative data between the two types of polymer are given in Figure 4.

The increased stiffness of this type of polyethylene has been exploited, particularly in the injection moulding field for applications such as buckets, bath racks, colanders, sink tidies, jugs, pipe fittings and lavatory syphons. Many manufacturers have found that they can obtain the right degree of rigidity or flexibility by using blends of high- and low-density polyethylene, the blending of the polymers being carried out by the moulder, commonly using pre-plasticiser injection moulding machines.

In comparison with low-density polyethylenes, the higher modulus of high-density types permits thinner wall mouldings without loss of rigidity, and with a consequent saving in raw material cost.

The higher crystallinity of the high-density polyethylene

results in an increase in tensile strength of the polymer. This is seen in Figure 5, where tensile strength is related to the polymer density. From the tensile strength figures quoted here, it is of interest to note that, although the high-density polymers are between 22 and 37 per cent more expensive than their low-density counterpart, there is almost a 100 per cent increase in tensile strength characteristics. The use of high-density polyethylene where strength is important is therefore often justified on purely economic grounds.

Piping, especially for cold water services, is an instance where high-density polyethylene has already gained considerable commercial success (see Figure 6). As the new high-density polyethylenes have enabled pipe with reduced wall thickness to be produced, the British Plastics Federation has recently drawn up a draft specification which will form the basis for a new British Standards Specification for high-density polyethylene pipe (see Table 2).

The high tensile strength of high-density polyethylenes has made it particularly suitable for monofilament production and, by drawing operations at elevated temperatures, orientation of the molecules produces a filament with strength characteristics approaching that of nylon. Good chemical resistance permits the use in the chemical industry of filter cloths woven from high-density polyethylene filament.

The chemical resistance of polyethylene of both high and low density is generally good. However, because of the lack of long-term field experience with high-density polyethylene, a strictly practical comparison between these two types of polymer is not possible. A great deal of work is being carried out to determine to what extent high-density polymers are affected by chemicals. Tables 3-5 give some of the results of these investigations.

Among commercial applications requiring high chemical resistance where high-density polyethylene has been used

TABLE 2. Wall thicknesses at a working pressure of 150 p.s.i. (temperature not exceeding 20°C.)

Nominal Bore	Wall Thickness according to specification	
	B.S. 1972	B.P.F.
¾ in.	0·173 ± 0·015 (in.)	0·096 ± 0·011 (in.)

TABLE 3. Chemical resistance of ethylene polymers at 23°C.

Chemical Environment	% Weight Change after 30 days immersion		
	Conventional	Ziegler	Phillips
Gasoline	+ 12·9	+ 6·2	+ 6·0
Ethyl Acetate	+ 3·07	+ 2·0	+ 2·1
Acetate Acid	+ 0·86	+ 0·60	+ 0·60
Sodium Hydroxide (50%)	Nil	− 0·01	− 0·01
Sulphuric Acid (98%)	− 0·02	− 0·02	− 0·02

TABLE 4. Time for 50% stress cracking in a 5% solution of sodium hydroxide at 50°C.

Type of Polymer	Average Molecular Weight	Time for 50% failure (hrs.)
	72,000	24
Ziegler	120,000	317
(density 0·95)	195,000	1029

TABLE 5. Comparison of stress cracking characteristics of extrusion grades of different polyethylenes.

Environment / Grade	Water	Sodium alkyl sulphate type detergent 20 % active	5% Sodium hydroxide	Acetic acid glacial	Ethyl alcohol
Conventional (density 0·92)	9,000 (hrs.)	20 (hrs.)	9,000 (hrs.)	50 (hrs.)	90 (hrs.)
High Density (density 0·95)	9,000	500	1,000	2,300	9,000

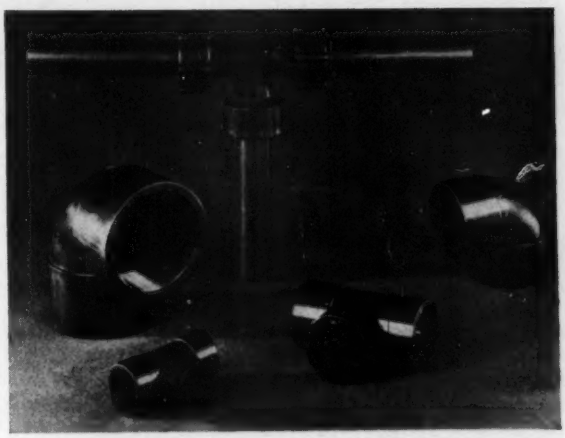


Fig. 6. Cold-water pipe fittings made of high-density polyethylene.
(Photo courtesy of Durapipe Co. and Yorkshire Imperial Metal Co.)

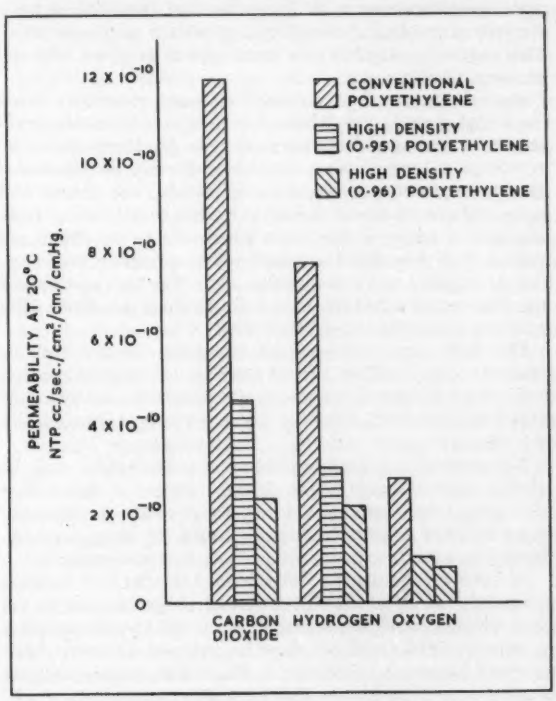


Fig. 7. Permeability of gases through polyethylene films.

TABLE 6—The effect of increasing molecular weight on impact strength.

Material	Molecular Weight	Impact Strength (Izod.) ¼ in. × ¼ in. bar ft. lb./in. notch
Ziegler	72,000	1·2
Polyethylene	90,000	1·4
Density	120,000	1·8
0·95g./cm.³	195,000	3·5

TABLE 7—Comparison of properties of thermoplastics.

Material Property	High-density Polyethylene	Conventional Polyethylene	Rigid p.v.c.	High-impact Polystyrene
Density g./cm.³ A.S.T.M. D1182-54	0·93–0·96	0·92	1·4	0·5–0·65
Tensile strength p.s.i. B.S. 1973:1953	2,800–5,000	1,500–2,000	5,000–9,000	3,000–5,500
Elongation at break% B.S 903:1950	500–900	200–750	2–40	10–40
Modulus of Elasticity p.s.i. × 10^5 A.S.T.M. D638 - 52T	0·5–1·5	0·19–0·35	0·35–0·6	0·35–0·55
Impact Strength ft. lb./ in notch ¼ in. × ¼ in. notch bar B.S. 903:1950	1·0–6·0	> 16	0·25–0·5	0·6–1·1
Coefficient of linear Expansion cm./cm./ °C.	12×10^{-5}	18×10^{-5}	7×10^{-5}	16×10^{-6}
Softening point °C. B.S. 1493:1948	106–125	80–90	75–80	70–100

are: ducting for chemical plants, bottles for the packaging of chemicals, beakers, funnels, lubricating oil containers and drum linings, kerosene containers, battery cases, and Aerosol containers and nozzles.

The use of high-density pipe for chemical plant work is of considerable interest, and pipes and fittings are now produced with their dimensions corresponding to those quoted in B.S. 1387. High-density pipe can thus be screwed into standard steel systems when corrosion troubles make replacement necessary, or it can be used (screwed or heat-welded) to produce a complete pipe system of this material. This type of piping has also been used in fertiliser and sulphuric acid plants.

Sheet with excellent chemical-resistant properties made from high-density polyethylene is now commercially available in a variety of thicknesses. It is produced either by extrusion or compression moulding. It may be fabricated into fume ducting and extraction hoods, vat linings and tanks for the chemical industry by the butt-welding technique. The edges of the sheet which are to be joined are melted and then fused together using a heating tool (e.g., hot air welding torch, hot plates, etc.). The tool is removed and the material hardens again to produce a welded joint which is as strong as the sheet itself.

The high impact strength of the sheet, coupled with its relatively great rigidity, should enable it to compete successfully on an economic basis with the products already established in this field, such as rigid p.v.c. and low-density polyethylene.

The permeability characteristics of polyethylene may be related fairly closely to the density. Figure 7 shows that high-density polyethylenes have, in general, permeability characteristics approximately one-third of those of low-density materials—an important factor in packaging.

In Europe high-density polyethylene lay-flat film is being produced, but large-scale commercial usage has not as yet been noticed, probably because of its relative opaqueness at present. This type of film is reported to have been accepted in some applications in the U.S.A. mainly because of its low permeability to gases and its suitability for "boil-proof" packaging.

The general toughness, i.e., resistance to abrasion and impact, of polyethylenes is dependent not only upon the crystallinity of the polymer but also upon the molecular weight. Abrasion resistance is conveniently measured by the Taber method. In this test the specimen is held in contact with a standard rotating disc of abrasive material and the weight of specimen removed after 100 revolutions of the disc is measured. Abrasion-resistance figures (Table 1) using this test method show that high molecular weight, high-density polymers have excellent characteristics in this respect, and this property has been utilised in a number of interesting ways.

Certain parts of textile machinery which are normally subjected to severe abrasion have been made from compression-moulded high-density polyethylenes of high molecular weight. Considerable work is in hand in the telephone cable field, where the greater toughness of this type of polymer will permit a significant reduction in the thickness of the cable insulation. This can be done without increasing the risk of damage to the wall during fabrication or installation of the cable. Such a reduction in wall thickness is of considerable interest, as it should allow more lines per cable.

Toughness of plastics is also dependent upon its impact resistance and, probably because of the more rigid nature of high-density polyethylene, this material shows poorer impact characteristics than the low-density type. However, its impact resistance improves with increasing molecular weight (see Table 6). For maximum impact properties, high-molecular-weight grades of high-density polyethylene should therefore be chosen.

The electrical properties of high-density polyethylenes given in Table 1 are not very different from those obtained with the low-density materials. Owing to present methods of manufacture, some of the high-density polyethylenes have marginally inferior power-factor and volume-resistivity measurements.

Expanding Use in New Fields

Up to now the electrical industry has been content to use the low-density polyethylenes, mainly because the electrical properties of this polymer have been proved so suitable. As a result, interest in high-density polyethylene has been devoted to those applications where the other properties (abrasion resistance, etc.) are more important.

But injection-moulded articles such as junction boxes, television dipole holders and cable clips are already being made of high-density polyethylene, and its use is expected to grow as the cable industry calls for insulation materials having better heat and abrasion resistance and greater rigidity.

In some of the high-density manufacturing processes (the Ziegler process in particular), the polyethylene is initially obtained in the form of a powder and this is ultimately extruded prior to granulation. This can be removed before the extrusion process and in this form it is finding increasing use in industry. Various sintering processes are now available for producing linings for drums, coating for chemical-resistant equipment and porous sheet (such as that used for water aerators).

The characteristics of high-density polyethylene in relation to other types of thermoplastics are shown in Table 7.

Because of the high tooling costs for moulds for new products, it is likely that high-density polyethylene may initially displace some of the conventional thermoplastics in articles of established design. However, in the long term, high-density polyethylene will tend to become complementary rather than competitive to these materials. In other words, consumption of both types of polyethylene and other plastics are expected to expand in fields where their particular properties make them most useful.

ORGANISATION OF A MODERN DRAWING OFFICE

The well-conceived drawing-office has become less of a rarity in recent years. This article sets out some of the important factors that contribute to good working conditions and output

Fig. 1. This new drawing-office of Girling Ltd. at Birmingham is a very fine result of converting and entirely re-equipping existing premises.

THAT maximum output and high quality of work from designers cannot be expected if working conditions and equipment in the drawing-office are of a low standard is still not fully realised by all engineering concerns. In recent times, however, more enlightened companies have given increasing thought to this side of their activities, and the last two or three years have seen the establishment in Britain of some outstanding examples of drawing-offices, efficient in operation and pleasant to work in; they will, indeed, compare very favourably with any in the world.

This will undoubtedly be a continuing trend and is likely to receive a stimulus when the Building Research Centre publishes towards the end of this year a report based on a wide survey it made some months ago of drawing-office layout and equipment, in the course of which members of its staff visited offices of various types and sizes throughout Britain. This is probably the first thorough and systematic study of the subject ever made in this country, and will certainly contribute to a wider appreciation of its less obvious aspects. But discussions on the planning and equipment of drawing-offices have been carried on among designers for years past, and this is perhaps an appropriate moment at which to sum up the views which are generally held and to describe how certain firms have recently endeavoured to put them into practice.

Fig. 2. Maximum use of natural light is made in this drawing-office of the Bowater Corporation Ltd. at Ellesmere Port.

It is simple enough to offer a definition of what the ideal drawing-office should achieve—high output of first-class work—but the nature of the work done by different industries calls for variations in drawing-office technique (for example, in the grouping of draughtsmen according to the work to be done) so that a standard layout is not practicable. However, the chief factors affecting morale and efficiency may be broadly summarised as lighting, equipment and environment and, as each can determine the standard and output of work, each demands the most serious consideration.

If one of these factors stands out above the rest, it is most certainly lighting. Ideally, one should work in a good natural daylight, but as this is limited by the shortcomings of the British climate and by the building itself, it is always necessary to make considerable use of artificial lighting. Even when plenty of daylight is available, this may need to be controlled with Venetian blinds to avoid glare, and artificial light may be needed to kill shadow. The tendency nowadays is to position fluorescent fittings in a pattern geared to the whole office, rather than for each board, making for greater flexibility. The Association of Engineering and Shipbuilding Draughtsmen, which has for many years striven for an overall improvement in drawing-office working conditions, recommends that there should be a minimum of one 5-ft. 80-watt fluorescent tube per drawing-board, mounted about 3 ft 6 in. above the board; if closed-top fittings are used, overhead filament lamps should be fitted.

The task of selecting new equipment presents many problems, despite the very broad range of excellent equipment that is available. In the small-to-medium office, an important consideration is the cost of equipment which must obviously bear a close relationship to its subsequent potential output. At the same time, the nature of the work

Fig. 3. Dazzle from fluorescent lighting is avoided by means of horizontal baffles in the ceiling of the Westland Aircraft Co.'s office at Yeovil.

Fig. 4. The entrance hall of the design office of Loewy Engineering Co. Ltd., near Bournemouth. Draughtsmen work on the upper floor and have a view over the enclosed grass court.

handled in the drawing-office can often determine the type of equipment selected. For example, for layout and other work demanding strict limits of accuracy, parallel motion draughting machines are usually selected, but where speed is more important, particularly in tool drawing-offices, the link-motion draughting machine is more commonly found.

The need for a satisfactory environment in which to work is nowadays appreciated widely at most levels. The physical aspects have been set down by A.E.S.D. as requiring a minimum space of 470 cu. ft. per person, exclusive of furniture and with a maximum calculating height of 10 ft. Other points, such as an adequate temperature (bearing in mind that a draughtsman's work usually involves little physical effort), suppression of noise and washing facilities do, however, have an effect that may not be reflected immediately in the work produced. Countless other factors in the mental well-being of the draughtsman spring more from an attitude than a definite policy of management. One chief draughtsman, for example, said recently of his office: "We hate petty rules here. We rely on the example of the older men to guide the actions of the new arrivals. For example, we don't check their time of arrival in the mornings or the accuracy of their overtime claims; we show that we trust them and this is not often abused. When it is, it usually happens that the man does not fit in well in other ways either."

Applying the Principles

It is interesting to find how well these principles have been adopted in the latest drawing-office to be completed in Britain, that at the Girling Ltd. head office near Birmingham. This is of particular interest, not only because of the attention which has been given to every important detail of lighting, equipment and environment but also because it shows clearly how a conversion of existing premises can provide excellent facilities without extensive reconstructional work.

The upper floor of the building which has been taken over has undergone a transformation. Formerly an irregularly-shaped area bounded by neutral-coloured walls and girders, this has now been completely redecorated, refurnished and equipped for the company's design office. An artificial ceiling of acoustic panels carries flush-fitted fluorescent lighting units and these provide all the illumination needed to supplement daylight. The steel supporting girders have been filled out to provide graceful pillars. These and the ceiling are in off-white and the walls are pastel green.

With the redecoration, the office has been entirely re-equipped with new pedestal drawing-board stands, steel desks (as reference tables), stools and storage cabinets—all finished in the same shade of pale green. Storage was originally in wooden chests, but drawings are now stored flat in steel cabinets. The office policy is to keep storage space to a minimum by a system of microfilm-recording older drawings which would otherwise need to be kept on file. Further work is currently going on to modernise the photo-copying section.

One impressive aspect of the Girling drawing-office is the strict attention that is given to small detail. For example, waste-paper bins have been specially designed by the company to fit on the Admel pedestal stands, so that there is no likelihood of disorderly appearance.

At present, more than 70 draughtsmen are housed in this drawing-office, but the recent alterations have taken account of the fact that the demand for space will continue to grow. Already, one end of the office has room to spare which could accommodate extra boards when the need arises, and this can be extended still further without impairing the efficiency of the section.

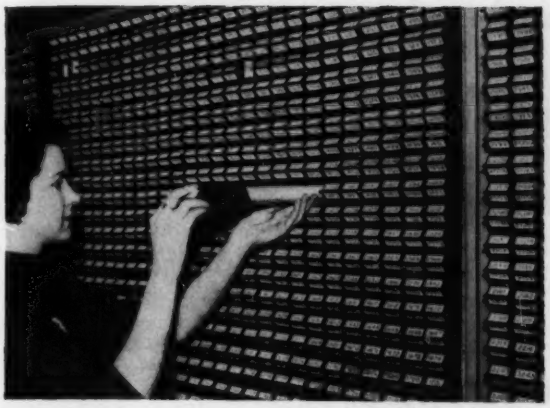
No consideration of good drawing-office principles put into practice can exclude the office building of Loewy near Bournemouth. Built just over four years ago, this is still a criterion of how the well-conceived drawing-office may be judged.

The specially-designed building is a two-storey glass and aluminium structure flanking four sides of a lawn, giving an impression (visual, at least) of a cloistered walk within. The drawing-office occupies the upper floor, where floor-to-ceiling glass walls permit maximum daylight to reach all boards, with blinds to prevent dazzle when required. Consultations with the Building Research Centre produced what were considered to be the most suitable lighting fittings in the best arrangement.

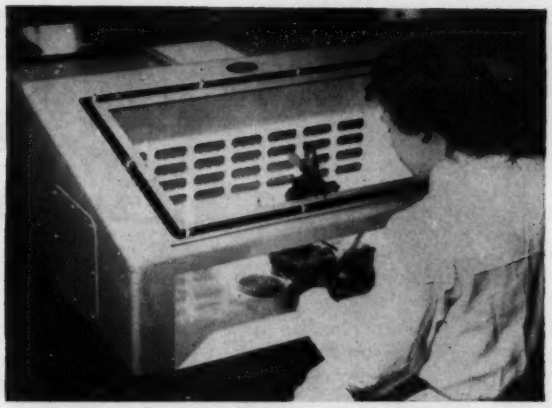
Despite the very fine appearance and facilities of the building, the cost of the office block was 45s. per sq. ft.; this Loewy claim with reasonable pride, was the lowest-cost office block of its size to go up in England since the war, because of the extensive glazing and limitation of brickwork.

The records section is housed on the ground floor where, for the hydraulics division alone, there are some 25,000 drawings stored mostly in conventional wooden drawers. Other systems of storage have been tried in the past, including those which involve hanging the drawings vertically, but the particular needs of Loewy decided in favour of conventional equipment.

While it is true that a great many design offices still fall short of the ideal, there are signs that a better understanding of their needs is on the increase. The well-planned drawing-office is less isolated than it was a few years ago, and it is to be hoped that many smaller engineering firms will adopt the policy of those larger concerns which see no wisdom in expecting good design from a poor office.



James H. Randall & Son Ltd. have designed a novel means for storing drawings in a sheet metal cabinet which is subdivided in a honeycomb fashion by steel reinforced fibre tubes of square section. The drawings are rolled and one end is gripped by a rectangular plastic cap. The other end is inserted in a honeycomb compartment leaving the end of the cap, which carries a reference label, easily visible.



The John Bass pressurised assembly cabinet has been designed specifically to overcome the problem of dust contamination, whether in a static or an airborne form. Pure air is constantly supplied under sufficient pressure to prevent contaminated air from entering, and the cabinet is fully illuminated and fitted with wide-vision plate glass which affords the utmost facility for work on small precision instruments and equipment.

BRITISH INVENTIONS' SUCCESS AT BRUSSELS

THE success of British inventors at the recent Brussels International Inventors' Exhibition was outstanding. Out of more than 1,500 inventors from all over the world, the small group of less than 50 British entries collected 26 diplomas, including the top award—The Grand Prix. The highest award and three other inventions which qualified for gold medals are illustrated here.

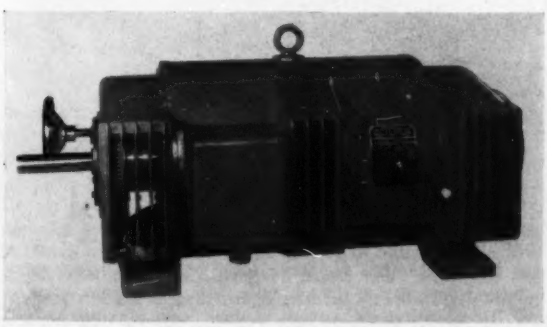
The British exhibitors are to be congratulated on having successfully upheld national prestige and inventiveness in design. It is expected that this will have beneficial results for British goods in world markets for, in addition to those mentioned, several of the inventors report interesting and promising inquiries. Nearly 20 leading German industrialists have written to the London headquarters of the Institute of Patentees and Inventors, asking to be kept in touch with its 1,400 members.

This success was all the more remarkable in view of the fact that until a few weeks before the exhibition was due to open not a single entry had been received from Britain. At the last moment, Mr. R. O. Sutherland, general secretary of the Institute of Patentees and Inventors, appealed to his members and succeeded in attracting 50 entries.

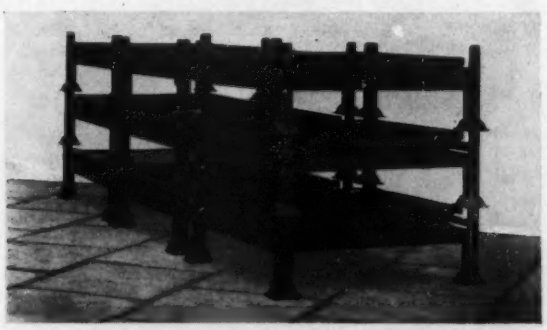
This years' exhibition was the seventh of the series and, with such a high proportion of successful entries from this country, it is to be hoped that inventors and manufacturers will be encouraged to enter in even greater numbers next year.

It is interesting to note that gold medals were given for so many engineering products, and this should stimulate engineering designers to come forward more freely in the future.

The apparent reluctance of inventors from this country to enter for this year's event may be partly due to the fact that it is not appreciated that entrants do not necessarily have to be inventors by profession. Engineers and designers in all industries may put forward exhibits.



Mr. Charles Brunt's variable speed a.c. motor, which took the Grand Prix, has a speed range of 100 to 1. It is operated by simple control gear and rotation can be reversed by simple hand wheel control without changing connections or switching. It is claimed to have excellent torque characteristics and is suitable for driving textile machinery, machine tools and it may also be suitable for traction purposes.



P. C. & C. K. Chase Ltd. have designed and developed these collapsible stacking stillages which have no loose parts and which are of robust construction, designed for simple and easy conversion. A stack of nine stillages is shown here collapsed, in which form they are ideal for returning as empties by road or rail transport. A standard range of sizes is available varying from 30 in. × 30 in. to 48 in. × 48 in. platform sizes.

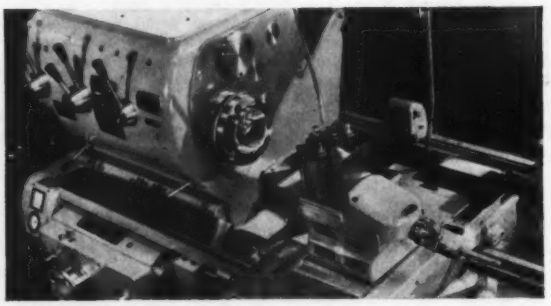
NEW IDEAS IN DESIGN

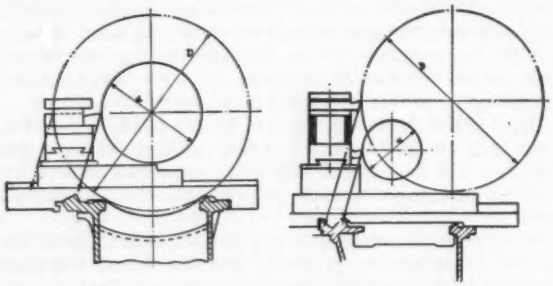
Interesting products in current manufacture

Adjustable Centre Height on a Copying Lathe

BY MOUNTING the headstock and tailstock on inclined slides, it is possible to increase the capacity of the Heid Neomat copying lathe by more than 50 per cent over the entire turning length. This adjustment, in the case of the headstock, is power-operated, the tailstock being operated by a handwheel. Re-alignment of the centres to 0·0003-0·0004 in./ft. is achieved by vernier scales, but still further accuracy can be achieved by means of a ground test bar and dial test indicator.

Packing up the headstock and tailstock of a centre lathe to accommodate outsize work usually results in poor finish on the workpiece, as the thrust on the tool falls outside the front slideway. By moving the workpiece upwards and away from the operator this is obviated and the workpiece surface finish is unaffected. The right-hand drawing (*see left*) demonstrates the principle involved.





Other features of the Neomat include: electric tracer control as an integral part of the machine; electromagnetic reversing clutches to control longitudinal and cross feed motions; electric precision limit switches which open after 0·004 in. displacement; Heid electro-magnetic multi-disc clutches, having no slip rings, for change of direction and braking; continuously oil-flooded guideways for the front saddle bearing, fully protected with telescopic stainless-steel guards; and a wide variety of accessories.

New Motor-cycle has Pressed Steel Main Frame Member

A BOX-SECTION girder, consisting of two deep-drawn pressings welded together and made torsionally rigid by a flanged diaphragm bolted in position at the open end, is the main structural feature of a new motor-cycle by Ariel Motors Ltd. The petrol tank is held inside by three screws. The front end of this top-frame member carries the steering head and the rear suspension dampers. The two-cylinder two-stroke engine and gearbox, which are in one unit, are bolted to underslung welded extensions of the main frame member by three long bolts, the lower rear of these carrying also the swinging arm of the rear suspension. By adapting the design, it has been possible to put all loads in the box girder, and eliminate the conventional tubular and plate fitting and attachments to the crank-case. At the same time, it has made the job of removing the engine and gearbox from the frame a simple operation.

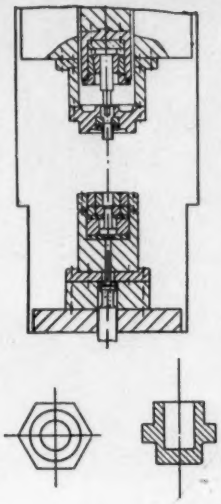
Extensive use of sheet metal guarding and removable panels results in good weather protection.

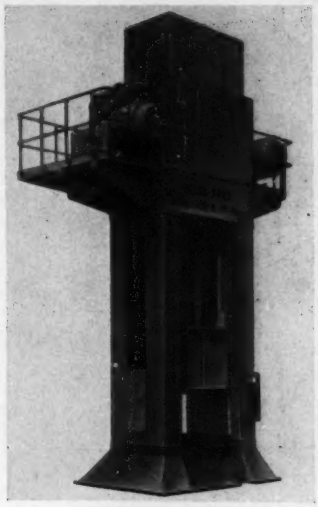
Hydraulic Double-action Cold Extrusion Press

A NEW hydraulic cold-extrusion press, designed in collaboration with the Production Engineering Research Association, is announced by E. W. Bliss (England) Ltd.

Principal feature of the press is a double-action motion, made possible by an inner and an outer slide. Forward and backward extrusions can be made, as well as a combination of the two. Features which simplify operation include a fully-automatic all-hydraulic push-button-control servo system, completely eliminating electrically-controlled valves. The increase in pressure in the circuit at the bottom of the press stroke operates a valve which returns the ram at a pre-set pressure.

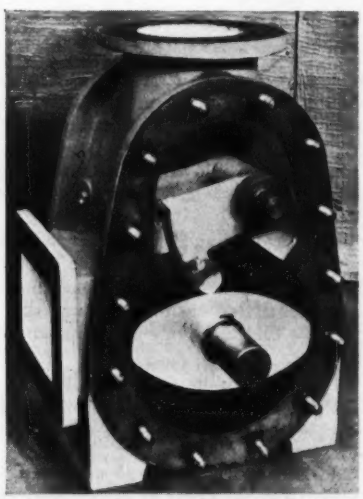
The sectional view (*right*) shows the tooling used to produce the typical example of combined forward and backward extrusion illustrated. The extrusion punch is fitted to the inner slide, the punch guide to the outer main slide. The sequence of operations, which is automatic, is as follows: Extrusion punch and guide advance rapidly together towards the component held in the die. At a predetermined point the advance is slowed and the first part of the extrusion, the forward part to form the spigot, takes place, together with a slight amount of backward extrusion. The main slide is then arrested and the inner slide advances with the extrusion punch to bring about a further amount of backward extrusion of the hollow portion of the component. When the punch has done its job, the component is automatically ejected by a hydraulic ram situated in the base of the machine and operated automatically as the extrusion punch retracts.





Although primarily designed for the cold extrusion of steel, this press can also be used for the impact extrusion of light alloys. Developed originally as a 300-ton press, it is offered also in sizes up to 1,000 tons.

Two New Valveless Industrial Pumps

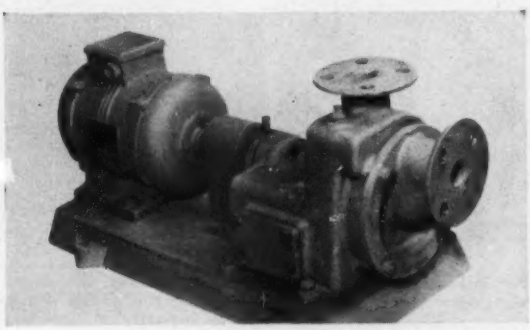


BY INCORPORATING the priming chamber and the volute casing in one casting, Girdlestone Pumps Ltd. have produced a small self-priming centrifugal pump (*right*) which takes up no more space than an ordinary pump of similar output. Known as the "Autostart", it works on the re-circulation principle and without valves. During circulation, air from the suction pipe is entrained in the liquid, and the air/liquid mixture is then passed from the volute to the specially-designed separating chamber. This allows air to pass through to the delivery pipe and the liquid to flow back through an orifice into the volute for re-circulation. This process continues until the suction pipe and pump are fully primed. After initial priming, flow back from the delivery pipe replenishes the priming chamber at the end of each operating period.

The cantilever-type shaft, running on deep-groove ball bearings, carries an open-type impeller which will carry small solids in suspension. The pump body is available in cast iron or in stainless steel and other resistant alloys. A variety of mechanical seals are available. At 3,440 rev./min. and 30 ft. total head the pump will deliver 1,000 g.p.h. (water).

The Amarilla rotary displacement pump (*left*), manufactured by George Fletcher & Co. Ltd., is of the positive rotary type and contains only two moving parts; namely, the rotor and the sealing arm, which is activated by the rotating rotor. The latter forms a seal and takes the place of a non-return valve.

Fluids containing a large percentage of solids can be passed without causing damage, either to the material or the working parts of the pump. The pump will handle sludge, heavy oil, semi-solids or thick slurries. It requires a drowned suction and will deliver against a pressure of 100 p.s.i.g. It is particularly competitive for fluids having a viscosity greater than 4,000 s.s.u. and will normally handle materials up to 90 deg. C. The pump can be supplied jacketed or unjacketed, and can be driven by belt or V-rope, or by direct-coupled electric motor through reduction gearing.



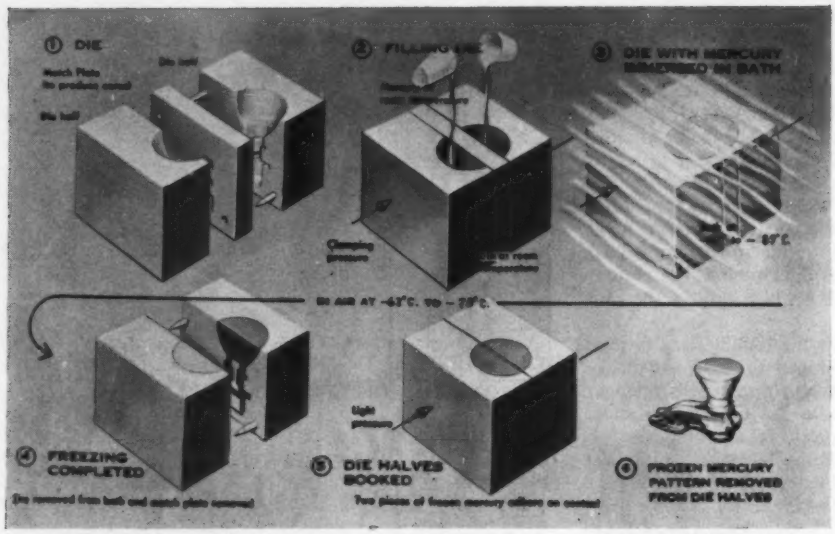

① DIE
② FILLING
③ DIE WITH MERCURY REMOVED IN BATH
④ FREEZING COMPLETED
⑤ DIE HALVES BOOKED
⑥ FROZEN MERCURY PATTERN REMOVED FROM DIE HALVES

Fig. 1. Stages in producing cored pattern.

FROZEN MERCURY PRODUCES HIGH-DEFINITION CASTINGS

USING frozen mercury as a pattern is an interesting and modern process for producing investment castings. In this country the Mercast process, developed by Sankey-Telcon, enables precision castings to be made to limits impossible by other techniques, and this process should be regarded as supplementary to the lost-wax method which it resembles in principle.

The frozen mercury process consists of pouring mercury into the metal mould and freezing it at about −65 deg. C. At this temperature it is possible to join two or more parts of the mercury pattern together with a slight impact pressure, the resulting joint being almost invisible. The mercury pattern, after being repeatedly dipped into a zircon-based refractory slurry, also at −65 deg. C., until a coating approximately ¼ in. thick is built up, is then dried under heat, during which the mercury runs out and is cleansed for re-use.

Fig. 2. Frozen mercury was used for this casting. Originally, the component (see background) was produced with lugs and stems for attaching the mating part.

The refractory is fired and, when necessary, backed up with cement mixture, after which the metal may be poured, using centrifugal, vibrating or vacuum techniques to ensure homogeneity of casting; vents in the mould are unnecessary, since the refractory is porous and allows any trapped air to escape.

It may be said that this process, although expensive because of the high degree of skill and accuracy necessary in preparing the metal moulds, is particularly suited to the following requirements:

1. High definition (corner radii as small as 0·005 in.)
2. Thin walls (wall thickness as low as 0·03 in.)
3. Complex shapes and re-entrant angles
4. A high degree of metallurgical control
5. High degree of surface finish (30-40 micro-in.)

The frozen mercury process is suitable for castings in various materials such as bronze, aluminium and high nimonic steels, and particularly for sizes exceeding 1 cu. in. volume. At −65 deg. C. the mercury has a stiffness comparable with that of lead, and is thus suitable where slender members are envisaged for which a wax pattern would be liable to sag.

From the cost angle, a production run of upwards of 100 components would be economical, and in considering the use of this process it is advisable for a designer to consult the manufacturers at the project stage, as by so doing he will be able to take full advantage of its particular features. A result of such co-operation is shown in Fig. 2.

MOLYBDENUM

(Mo) — Purity — 99·99 powder metallurgy
99·96 arc cast

PHYSICAL PROPERTIES

Density at 20°C

Pressed:	6·1-6·3 gm./cm.³
	0·221-0·228 lb./in.³
Sintered:	9·2-9·4 gm./cm.³
	0·333-0·340 lb./in.³
Drawn:	10·0-10·3 gm./cm.³
	0·362-0·372 lb./in.³
Specific Gravity:	6·1-10·3
Melting Point:	2,622 ± 10°C.

Specific Heat

$\left(0{\cdot}06069 + 0{\cdot}000012T - \frac{361}{T^2}\right)$: 0·058 cal./gm. at 0°C.
0·075 cal./gm. at 475°C.

Electrical Conductivity: 36% IACS

Magnetic Susceptibility: + 0·04 × 10^{-6} cgs. at 18°C.

MACHINING PROPERTIES

Cutting tool	...	high-speed steel or tungsten-carbide
Tool angles...	...	as for cast iron
Depth of cut	...	not less than 0·05 in.
Cutting speed	...	up to 100 ft./min.
Cutting oil	...	sulphur-based
Threading ...	...	rolling preferable to cutting

(Molybdenum is prone to chipping and therefore work and tools must be rigidly held.)

CORROSION:

Negligible or slow reactions to most chemicals at room temps.

Unaffected by air, oxygen and water at room temps.

Rapid oxidization in air and oxygen above 450°C. and in water vapour above 700°C.

May be clad to prevent oxidisation at elevated temps. Examples of suitable cladding material are nickel, stainless steel, iron alloys, glass, silicon, aluminium, gold.

USES:

Dies and furnace crucibles — Chemical industry
Bi-metals and thermocouples — Tips for spot welders
Metal-to-glass seals — Heating elements in furnaces
Components for heat engines — Electrical conductors
Alloy constituent of steel (increases hardenability and toughness)
Wire and sheet in lamps and thermionic valves
Punches for hot piercing of billets and seamless tubes
High-temperature nozzles and turbine blades

FABRICATING PROPERTIES

As Mo is primarily a sintered material, powder metallurgy techniques can be employed.

Soldering: Electro-plate surface with nickel or copper prior to using conventional soft solders

Brazing: Use silver flux, preferably in inert atmosphere. (Improved joint by electroplating surfaces with nickel or copper prior to brazing.)

Welding: Resistance spot welding; Fusion welding by argon arc; Pressure welding — Embrittlement over welded area

Spinning: Approx. 500 ft./min. peripheral speed
Lubricant—tallow
Forming tools—aluminium bronze
Spinning temperatures—up to 400°C.

Sheet Material:

22 s.w.g. and thinner	work at room temp.
22 s.w.g. to 18 s.w.g.	work in temp. range 90-160°C.
Above 18 s.w.g.	work in temp. range 482-538°C.

Tubes:

Flaring	work at temp. approx. 538°C.

Coiling—
Up to ¼ in. o./d. × 22 s.w.g., coil in temp. range 90-177°C.
Above ¼ in. o./d. × 22 s.w.g., coil in temp. range 482-538°C.

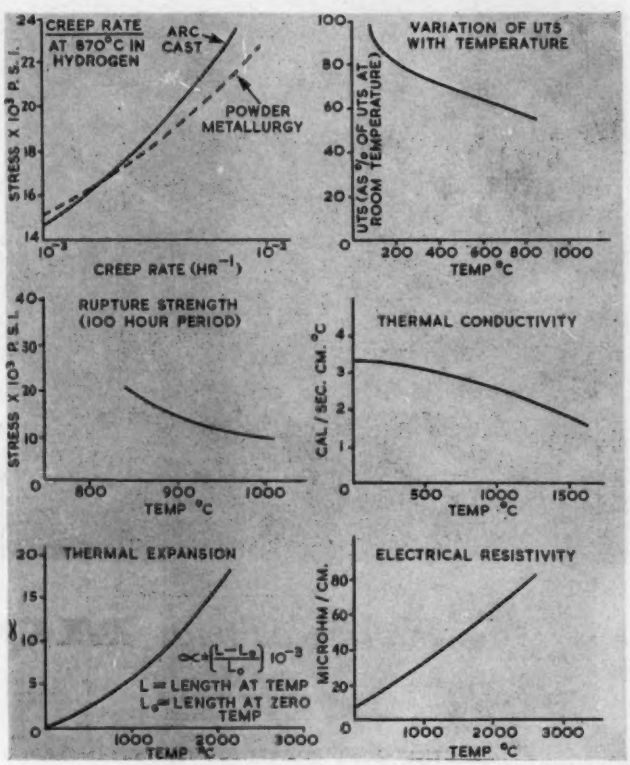
Engineering Materials and Design
DATA SHEET

MECHANICAL PROPERTIES

Modulus of elasticity: 45—46 × 10^6 p.s.i. Hardness VPN: 17P—280

(at room temp.)	U.T.S. p.s.i.	YIELD POINT p.s.i.	ELONGATION % max.
Hard-drawn wire	200,000-310,000 (at 0·005-0·0015 in. dia., increasing with reduction of gauge)	—	25
*Arc-cast and annealed bar	73,600-100,100	50,100-99,800	55-32
*Arc-cast, hot rolled and annealed sheet:			
Straight-rolled	105,400-116,500 (longitudinal)	99,500-102,400	22-12
	115,400-124,000 (transverse)	—	14-8
Cross-rolled	107,800-125,100	102,800-123,500	22-12
Arc-cast, cold rolled sheet	78,800-154,300 (longitudinal)	75,400-151,800	39-5
	83,200-132,100 (transverse)	76,800-130,200	22-3
(at elevated temps. tested at 1,066°C.)			
Arc-cast hot rolled bars—			
As rolled	38,000	22,800 (0·2% proof)	
Stress relieved	31,400	22,800 (0·2% proof)	

* *Properties vary with annealing temps.*



A NICKEL STORY

Pride of possession, as well as a face is reflected in the mirror finish of really good plating. For sound decorative chromium plating a nickel deposit approximately a hundred times the thickness of chromium is the only foundation which will give years of satisfactory service, against corrosion, rubbing and knocks. Ask Mond about this aspect of the nickel story. Mond have the resources for research and development and supply technical publications for guidance in the choice and use of modern materials.

Enough Nickel for all needs—

Plan ahead with **MOND NICKEL**

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TGA GN33

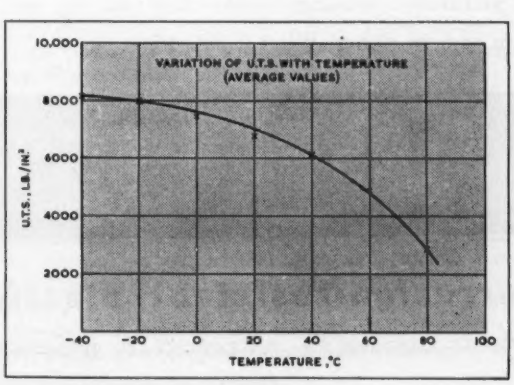
Engineering Materials and Design

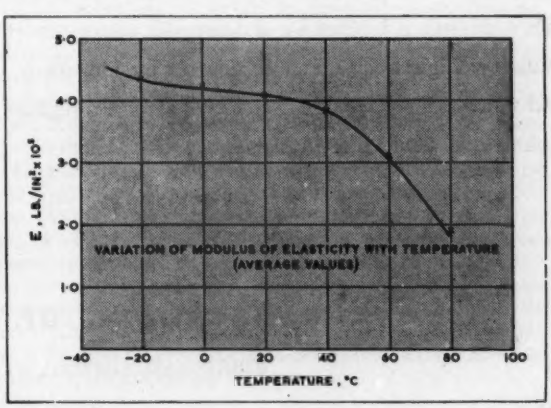
DATA SHEET

POLYSTYRENE

(Average values quoted)	UNITS	GENERAL-PURPOSE POLYSTYRENE	TOUGHENED POLYSTYRENE	HIGH SOFTENING POLYSTYRENE
MECHANICAL PROPERTIES (at room temperatures)				
Ultimate tensile strength	p.s.i	6,000–6,750	3,500–5,000	6,250–8,300
Elongation at break	%	1·5–2·0	15–30	1.5–2·0
Flexural strength	p.s.i.	10,000–14,000	6,000–8,500	11,000–12,500
Deflection at break (3-in. span, bar 5 in. × ½in. × ¼ in. deep)	in.	0·2–0·35	>1	0·3
Modulus of elasticity (tension)	p.s.i.	4–5	2·5–3.5	3·5–5·5
Izod impact strength	ft. lb./in. of notch	0·25–0·50	1·3–1·8	—
Hardness	Rockwell	M65–M80	M30–M65	M70–M80
Compressive strength	p.s.i.	14,000–16,000	—	—
THERMAL PROPERTIES				
Specific heat	cal./g./°C.	0·32	0·32	0·32
Thermal expansion	in./in./°C. × 10^{-5}	6–8	6–8	6–8
Thermal conductivity	cal./sec. cm. °C × 10^{-4}	1·9	(3·4–4·3)	—
Heat distortion temp. (to ASTM D648–45T) 66 p.s.i. fibre stress	deg. C.	85–90	79	94–96
Softening point (to B.S. 1493: 1948)	deg. C.	90–93	84–86	97–103
ELECTRICAL PROPERTIES				
Power factor at 10^6 cycles per sec.	—	0·0002–0·0010	0·0007–0·0010	0·0005–0·0010
Permittivity (power factor at 10^6 cycles per sec.)		2·45–2·60	2·65	2·45–2·65
Surface resistivity	ohm	$>10^{15}$	$>10^{15}$	—
Volume resistivity (to ASTM D257–57T)	ohm–cm.	$>10^{13}$	$>10^{13}$	$>10^{-13}$
Electric strength	volts/mil	>400	>400	—
GENERAL				
Specific gravity		1·05–1·07	1·05–1·07	1·05–1·07
Density	lb./in.³	0·0379–0·0387	0·0379–0·0387	0·0379–0·0387
Refractive index	n_D^{25}	1.59	1·59	—
Moisture absorption (ASTM D570–54T)	%	0·03	0·05	—
Water vapour transmission (moulded 0·060 in. sheet)	grains/100 in.²/24 hr.	0·128	—	—
Corrosion and chemical resistance	Alkali	—	Resistant	
	Acid	—	Attacked by strong oxidising acids	
	Water	—	Resistant	
	Oxygen	—	Resistant	
	Solvents	—	Soluble in esters, aromatic hydrocarbons, higher alcohols and chlorinated solvents	
Inflammability	*Burns readily with smoky flame, material drips and flows during burning.*			

Note: The properties quoted above are average values in each case for polystyrene and styrene copolymers of the grades indicated.
A direct tabulation and comparison of the materials commercially available is not practicable due to the wide variety of test methods employed and quoted by individual manufacturers.
Manufacturers of polystyrene moulding compounds in the U.K. supplying materials of the types indicated are: British Resin Products Ltd., Distrene Ltd., B.X. Plastics Ltd., Erinoid Ltd., Styrene Products Ltd., Kleestron Ltd., and Monsanto Chemicals Ltd.





Resin suppliers: British Industrial Plastics

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NEW ALLOYS INCREASE TITANIUM'S VERSATILITY

FROM OUR OWN CORRESPONDENT

ANNOUNCEMENT of three new titanium alloys has just been made by Crucible Steel Co. of America. Known as Crucible C-115AMV, C-105VA and B-120VCA, the alloys are expected to open up promising new applications for titanium.

The basis for developing the C-115AMV alloy (4 aluminium-3 molybdenum-1 per cent vanadium) was to provide a material that could be easily formed in the solution-treated condition and subsequently aged to high strength levels with adequate service ductility. This alloy has shown considerable promise for aircraft sheet applications requiring excellent formability and a heat-treated strength of 170,000 to 190,000 p.s.i. ultimate, with about 6 per cent elongation. In this condition the alloy shows excellent creep resistance and good creep stability to about 425 deg. C.

The C-105VA alloy (16 vanadium-2·5 per cent aluminium) is an alpha-beta type titanium alloy which is designed to (1) be soft and ductile and easily formed, and (2) possess the high strength and elevated temperature properties demanded by future airframe and missile components for use up to 425 deg. C. Tentative mechanical property limits established for the new alloy are: ultimate tensile strength—90,000 p.s.i. minimum, yield strength—75,000 p.s.i. maximum, and a minimum elongation of 12 per cent in 2 in.

The third alloy, B-120VCA (13 vanadium-11 per cent chromium), is claimed to be the most versatile titanium alloy yet developed. It is said to have the highest strength and best formability of any titanium alloy. It is ductile-weldable, cold-headable, and it has deep hardenability. These properties appear to make it ideal for high-strength honeycombs as well as thick heat-treated sections. The outstanding properties of the alloy result from its highly alloyed beta titanium structure. Typical minimum mechanical properties of annealed sheet are: ultimate yield strength—125,000 p.s.i., yield strength—120,000 p.s.i., and an elongation of 10 per cent in 2 in.

Stress Corrosion Cracking in Aluminium Bronze

Development of a new alloying technique by Ampco Metal Inc. is claimed to eliminate the problem of stress corrosion cracking in aluminium bronze. After considerable experimentation with various processing methods and alloy additions, it has been found that the addition of exactly one-third of 1 per cent of either tin or nickel to aluminium bronze can prevent stress corrosion cracking in steam environments.

Known as Ampco Grade 8, the new aluminium bronze alloy has been tested in dozens of field applications without a single failure. Previously-used aluminium bronzes possessed outstanding corrosion resistance and high strength, but spontaneous cracking failure frequently occurred in the presence of steam.

The development is expected to place aluminium bronze in direct competition with nickel-bearing and stainless steel alloys for many corrosive applications. Typical of the applications in which the new alloy can be successfully used are steam equipment such as paper mill drier rolls, brewery percolators, chemical plant heat exchangers or sea-water evaporators. Also, a wide range of distillation equipment such as fractionation towers and equipment for processing sulphuric and acetic acid, formaldehyde, caustics, furfural and chlorinated hydrocarbons. In addition, the alloy can be used for high-temperature piping. It is now permitted for use in pressure vessels approved by the American Society of Mechanical Engineers. Allowable working stress is 10,000 p.s.i. at temperatures up to 260 deg. C.

New Fluoroelastomer for High-temperature Use

A new fluorinated rubber with a possible −55 deg. C. to 315 deg. C. service temperature range and exceptional resistance to fluids is now commercially available from E. I. du Pont de Nemours & Co. Inc.

Called Viton, the material is a copolymer of vinylidene fluoride and perfluoropropylene. Viton retains useful elasticity for more than 2,400 hr. at 200 deg. C.; 1,000 hr. at 230 deg. C.; 72 hr at 290 deg. C.; and 24 hr. at 315 deg. C. It is more resistant to more fluids than any elastomer known today. It is resistant to aromatic and aliphatic hydrocarbons, aromatic amines, chlorinated hydrocarbons, dilute and concentrated mineral acids and alkalis, petroleum hydrocarbons and water.

Viton is the third fluoroelastomer to become commercially available in the U.S. The other two are Kel-F Elastomer, produced by Minnesota Mining & Mfg Co., and Silastic LS-53, produced by Dow Corning Corp. Of the three, Viton appears to be suited for the most severe combination of service conditions of temperatures and degrading fluids.

Two other fluoroelastomers now under development are Fluoro-Rubber 1F4, produced by 3M, and a fluorinated polyester rubber under development by Hooker Chemical Corporation.

Foamed Silica for High-temperature Insulation

A rigid, closed-cell refractory foam material, consisting of 99 per cent pure fused silica has been developed by Pittsburgh Corning Corp., primarily for high-temperature thermal insulating applications. Useful over a temperature range of −260 deg. C. to 1,200 deg. C., the material is reported to be unaffected by all acids except hydrofluoric and hot phosphoric. It should be protected against caustics.

Trade-marked Foamsil, the material's thermal conductivity (k) ranges from 0·48 to 1·85 B.t.u./sq. ft./hr./°F./in. over the temperature range of 40 deg. C. to 480 deg. C. Insulating value of one inch of the material is said to be equivalent to that of 18 in. of acid brick at temperatures of 120 deg. C.

Foamsil has a coefficient of thermal expansion of about one-eighth that of low carbon steel, which provides excellent thermal shock resistance as well as providing a high degree of volume stability throughout its entire operating temperature range. It also has good dimensional stability in that it does not warp, shrink or slump during rapid temperature changes. Densities range from 10 to 12 lb. per cu. ft. and provide compressive strengths of 130 to 210 p.s.i. Foamsil is available in blocks, 11 × 17 in. or 17 × 22 in., in thicknesses up to 3 in.

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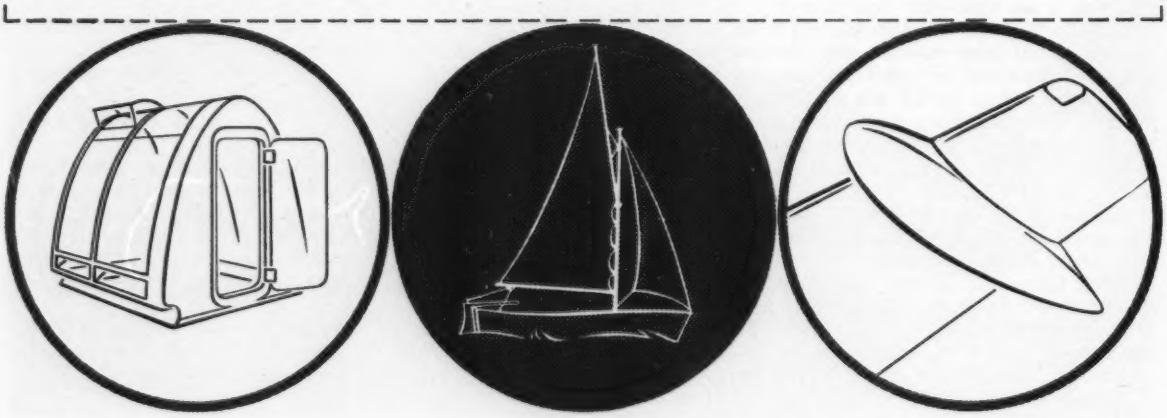

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AVAILABLE FROM U.K. PRODUCTION

WHAT'S NEW IN MATERIALS

Woven Heating Element

A woven-glass fabric on which graphite has been deposited forms the basis of a new kind of low-temperature heating element announced by Hunting Mhoglas Ltd. Its resistance, expressed in ohms per unit square, can be varied by the number of coatings on the glass fabric. The thickness of the deposit, the resistance of which can vary between 6 and 100 ohms, is of micro dimensions. Contact with the ends of the fabric is made by steel spraying. The flexible element produced is then treated with one of a series of thermo-hardening resins, normally of the epoxy type. The type of resin used imposes a restriction on the maximum working temperature for which the element is suitable, i.e., approximately 200 deg. C. The manufacturers

point out, however, that this temperature can be considerably exceeded when the element is used intermittently.

The advantages claimed for this novel material, called Mhoglas, are that it is light and flexible, has a non-metallic conductor, can be easily cut, shaped, bent and formed, is inexpensive, and can be potted or incorporated as a lamination in wood, plastics, rubber, concrete or metal. The absence of local hotspots enables it to be used in conjunction with combustible materials, and renders it particularly suitable for domestic applications involving a fire risk. Successful applications include heated elements for aircraft production, platen-heating fixtures for softening thermoplastics, polyethylene heat-sealing tools and heated panels, skirting boards, ducting, tables, etc. It would also appear to have possibilities for such uses as the pasteurising of milk, incubators, frost prevention and maintaining temperature in large vessels.

EMD 78 for further information

Plastic-clad Metal

A material which offers new opportunities to many industries is produced by Miles Druce Steel Ltd. This material, called Skinplate, consists of a metal sheet covered on one side with a p.v.c. film which is resistant to mechanical abrasion and chipping as well as detergents and many chemicals. Skinplate unites the properties of plastics with those of the metal sheet, which may be steel, aluminium or magnesium; it can be worked in the same way as normal sheet and can be sheared, perforated or bent. It is suitable for deep drawing and may even be welded without damaging the plastic film using a special technique. It has numerous applications for ducting, hoppers for machines, containers for corrosive liquids and for structural parts subject to corrosion.

EMD 79 for further information

Plastic Protective Fluid

A synthetic resin emulsion, Pitaplan, made specially for coating all types of paper is available from Caulking Services Ltd. It is applied by brush, spray, immersion or roller and dries in a few minutes. It is resistant to metals, greases and general dirt, which can be quickly removed by soap and water or petroleum spirit. It is particularly recommended for the protection of engineering drawings and plans, electrical circuits, diagrams, operating instructions and cards for machines and plant.

EMD 80 for further information

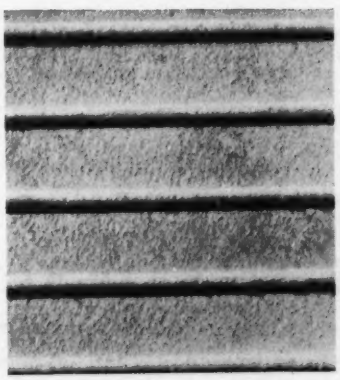
Heat-resistant Styrene

Polectric SM11 is a thermoplastic styrene copolymer developed for use as a high-temperature dielectric, but has other applications, such as light filters and transparent articles which must be steam sterilised. The electrical, mechanical and chemical properties are similar to polystyrene, but the softening point is not less than 130 deg. C. and it is claimed that for most applications it can be used continuously up to 120 deg. C. The material is supplied by Lucent Products Ltd.

EMD 81 for further information

Heat-shaped Fabric

Union Carbide Chemicals Co. of New York are producing heat-shaped fabric of Dynel Acrylic fibre. The shaping is carried out by forcing a cold mould into the fabric, which is clamped around its periphery and then it is heated. After cooling, the fabric is removed and trimmed. The material is available as woven fabric or as a non-woven felt. Among the interesting applications suggested is the manufacture of battery separators, industrial flange and valve covers and protective packing for delicate instruments.



EMD 82 for further information

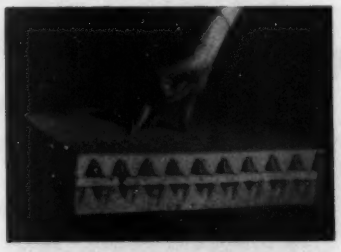
Immersion Gold Solution

Engelhard Industries Ltd. have introduced a new "Atomex" immersion gold solution for depositing a thin layer of 24-carat gold. A wide range of metals may be coated by simple immersion in the hot solution for a few minutes. The amount of gold deposited is dependent on the temperature and the base metal being coated. Theoretically, all metals below gold in the electromotive series can be coated by this method. Apart from decorative effects, this process has many applications in the protection of metals. For instance, it is claimed that copper-foil printed circuits retain their solderability for 12 to 18 months when protected with a gold plating a few millionths of an inch thick.

EMD 83 for further information

Foam Plastic

A new expanded plastic called Foamoprene has recently been introduced by Kay Bros. and is already being used in a wide range of industries. It is sponge-like in form, extremely light and elastic



by nature and is available in a range of densities from 0·028 to 0·055. It is claimed to be unharmed by water, air, petrol, grease, detergents and disinfectants and will resist weak acids and alkalis as well as most solvents. It can be rendered flame-proof and can be produced in a special tear-resistant form.

EMD 84 for further information

Zinc-rich Primer

Zinc coatings have long been recognised as being most effective for protection of iron and steel against corrosive influences, but the better-known methods of application, such as hot dipping and electro-plating, are not always applicable. Allweather Paints Ltd. have recently introduced the Fitanode wet primer which can be applied under almost any conditions to site steelwork or for the maintenance of equipment already in service. The high zinc content of this paint protects the iron by cathodic action so that small cracks and pin holes, due to abrasion or faulty application,

continued on page 53

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WHAT'S NEW IN MATERIALS

continued from page 51

will not result in the spreading of corrosion underneath the coating. Pitanode is particularly recommended by the makers for iron or steel exposed to marine atmospheres.

EMD 85 for further information

Steel for Vitreous Enamelling

A new pre-coated steel for vitreous enamelling is announced by John Summers & Sons Ltd.; known as Nitec, it consists of an enamel grade sheet steel base, which after annealing and cleaning is coated with nickel and a final protective coating of zinc. As Nitec need only be pickled for three minutes, during which time the zinc coating will be removed and the steel degreased, considerable time is saved in the pre-treatment of the steel before enamelling, as no further operations are necessary. The protective coating of zinc prevents rusting of the sheets during storage, and it is also claimed to enhance tool life and assist deep-drawing operations.

EMD 86 for further information

Aluminium Strip

A new aluminium strip called Ano-Coil has recently been introduced by Acorn Ano-coil Ltd. It is supplied in coil form and has a continuous anodised ductile surface film which will withstand reasonable deformation. It is available in a range of finishes from electro-brightness to satin and in a wide range of colours. Widths up to 20 in. can be supplied in gauges from 0·003 in. to 0·028 in, of any temper. This material would appear to have great possibilities in the electrical field, where the good insulating properties of an anodic film and its high-temperature resistance can be utilised.

EMD 87 for further information

Non-woven Fabrics

A new form of fabric having no warp or weft may have interesting possibilities in insulation and other engineering applications. The material is made up of a layer of fibres, bonded with a chemical adhesive and, as the fibres have a random distribution, the fabric has equal strength and stretch in all directions. The material is produced by Lantor Ltd. and is available in a wide range of thicknesses and colours. It has been suggested as a reinforcement for plastics and laminates. Blends of nylon and other selected man-made fibres are available.

EMD 88 for further information

Plasticiser Resin

British Resin Products Ltd. has recently introduced a new resin, Cellobond A2591, an amber syrup of low viscosity specially developed as a plasticiser for rigid polyester resins. It is completely miscible in all proportions with other resins of its kind and gives them a degree of flexibility proportional to the amount used. In gel coats, its addition to other Cellobond polyester resins will increase impact resistance and minimise any tendency to craze on impact. Because it is an unsaturated resin, it will cure when a catalyst is added. When it is used to plasticise other polyester resin mixes, the plasticising resin is firmly linked to the rigid resin and cannot migrate.

EMD 89 for further information

New Lead Alloys

British Lead Mills Ltd. have developed a new lead alloy, Antatac R1, to counteract troublesome failures in tank linings used in the chromium-plating industry. Over 200 different alloys were examined during the investigation and it was found that Antatac R1 was the only lead alloy which was not attacked by chrome-plating solutions under conditions of severe misuse. The new lead alloy is available in the form of sheet, pipe and anodes.

EMD 90 for further information

Bright Nickel Plating

A new process for bright nickel plating, named Plusbrite, has been announced by Albright & Wilson (Mfg.) Ltd. The advantages claimed for the new process are excellent levelling properties together with a fully-bright deposit which has a good degree of ductility. The process has many applications for a bright finish, having improved physical properties for electrical appliances, steel pressings, forgings and zinc base die-castings as well as brass and copper parts.

EMD 91 for further information

Wire Insulation

Secon Metals Corp. has developed several insulations which can be applied to wire for high-temperature use. One of these is a bonded ceramic which is good for continuous use up to 315 deg. C. and for intermittent use up to 430 deg. C. The other is a pure ceramic insulation which is good for continuous use to at least 650 deg. C. and for short-term use at higher temperatures.

Both of these insulations are flexible so that they may be wound readily on mandrels.

The 650 deg. C. insulation is supplied in a semi-cured condition. This must have a heat treatment before it is ready for high-temperature use. It must be cured for two hours at 430 deg. C., followed by a ten-minute curing at 570 deg. C., after which the coil is ready for use.

EMD 92 for further information

FOR MORE INFORMATION
about any of the products mentioned on these pages, please use the special reply card provided.

READERS' ADVISORY SERVICE
We shall be pleased to help readers who have difficulty in tracing sources of supply of materials or components.

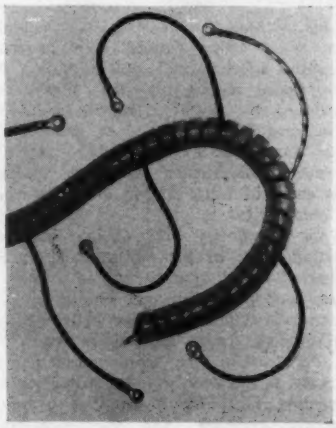
P.v.c.-covered Tubing

A wide range of steel, plastic-covered tubing is now being produced by LaBurn Ltd. for use as conduit for electrical work or for where external corrosive conditions exist. Almost any colour can be supplied in tubes or rods up to 3 in. dia. Makers claim that tests with the tubing have shown that its thermal conductivity is 0·004 cal./cm.²/cm./sec./°C. compared with unprotected steel (0·18 cal.) and zinc (0·27 cal.).

EMD 93 for further information

Spiral Tubing

Polyethylene tubing is now being specially manufactured by Hellermann Ltd. as a wound coil spiral. This material has been developed as a result of the demand for a flexible insulated sleeve



which can easily be fitted in inaccessible positions. Individual wires may be taken from the cable harness at any point without removing the cable or modification to the insulation.

EMD 94 for further information

New Brazing Alloy

A new series of nickel-base alloys is being made by Dewrance & Co. Ltd., which offers good mechanical properties and high resistance to oxidation, wear and corrosion at both low and high operating temperatures. They can be used for brazing austenitic and stainless steel, Nichrom, Inconel and other high nickel or high cobalt base alloys and techniques have been developed for dealing with refractory oxides and precipitation hardening alloys. Most metals with melting temperatures over 1,100 deg. C. can be brazed successfully. Joints made with these alloys have mechanical properties, corrosion and oxidation resistance similar to the stainless and heat-resistant alloys with which they are used, and their wide range of fluidity meets different brazing and service conditions.

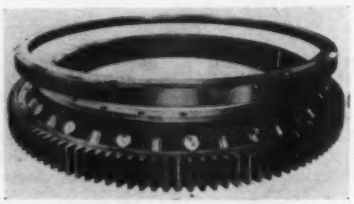
EMD 95 for further information

WHAT'S NEW IN COMPONENTS

Slew Bearings

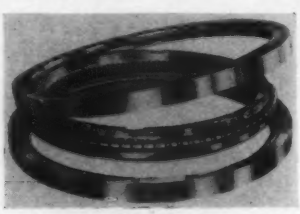
Two recently-developed anti-friction bearing rings make it possible to eliminate the cumbersome centre post and hook roller in full circling cranes and excavators and, at the same time, achieve a stronger and more compact mechanism.

The Priestman Cross-Roll bearing, developed in collaboration with British Timken Ltd., uses tapered rollers. Four separately machined rings (the inner pair bolted to the revolving superstructure, the outer pair to the crawler frame) contain between their inclined hardened



faces the staggered rollers, the surrounding space being packed with extreme pressure lubricant. Complete sealing of the space containing the rollers is achieved by synthetic rubber seals of cruciform section carried in grooves in the superstructure and the crawler frames. Still further protection against the entry of water or grit is ensured by a grease-filled labyrinth, fed by nipples in the upper ring, while O-rings seal the mating faces of the rings. All play is eliminated by spacing shims between the inner pair of rings. The cross-roll bearing is at present in use on Priestman full-circling cranes and excavators.

The Roballo ring, employed in Coles Cranes, is marketed by the Roballo Engineering Co. Ltd. It employs a ball-bearing principle and the manufac-



turers state that absolute sealing is not necessary for crane work, but can be provided if required. These bearings can be manufactured to suit the particular requirements of a customer, up to a diameter of 13 ft.

Although primarily designed for use in cranes, both of these rings should have many other applications. The problem of how to rotate large masses where heavy tipping moments occur is a common one. Compact rings of this type should be of interest to designers of machine tools (e.g., for vertical boring machine tables, turntables for automation set-ups, welding positioners), chemical plant and food mixers.

EMD 96 for further information

New Universal Joint

The Harris universal joint manufactured by F. & T. Kitchin consists of only two parts (the driver and the driven member) and a ball which serves only for accurate positioning of the two main members and which is not under torsional stress. The angular range of the joint is 40 deg. and it is claimed that the direct contact, which is of a rolling nature, between driver and driven members with the elimination of the usual intermediate, enables a high efficiency to be maintained at high speeds.

EMD 97 for further information

Stainless Valves

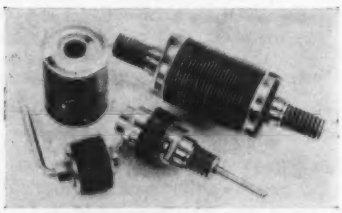
Stainless-steel bellows-sealed valves in a range supplied by Appleby & Ireland Ltd. are primarily designed for use in controlling nuclear materials, especially corrosive media, where absolute leak-tightness is imperative. The valves are Argon-arc welded and are leak-tested by means of the helium leak tester. They can be used in separating plants for separating radioactive materials such as heavy water and plutonium, liquid metals—sodium-potassium and sodium—up to a maximum of 580 deg. C., and helium and carbon dioxide up to 250 deg. C. and 350 p.s.i. Metal-to-metal seating is normally employed but valves with p.t.f.e. seatings can be supplied for controlling fluorised material.

EMD 98 for further information

Welded Bellows

Specially-developed bellows which permit designs that are 25 to 50 per cent smaller than conventional bellows have been developed by Robertshaw-Fulton Controls Co., Connecticut. Known as the Formweld bellows, assemblies are available in small or large production runs in metals such as AISI 300 and 400 series stainless steel, inconel-X, Ni-Span-C, titanium, zirconium and other weldable, non-ferrous materials.

They are built of individually welded plates and may have many more convolutions per inch of length than conventional, hydraulically-formed bellows. This, coupled with the precision inert gas welding process and the resistant



characteristics of special metals used, is claimed to result in a precision-controlled effective area and a lower spring rate. Thus, instruments achieve greater reliability, uniformity and sensitivity under all types of operating conditions.

EMD 99 for further information

Internally Geared Pulley

The Andantex, a reduction pulley containing a planetary gear system running in oil on ball and roller bearings, providing a compact speed reducer for direct mounting on the driven shaft, is announced by Furnival & Co. Ltd. To ensure equal tooth loading, on the hardened and ground planetary pinions, the reduction unit is permanently assembled by moulding a nylon sleeve *in situ* between each gear and its shaft. Semi-circular grooves in bore and shaft, into which the nylon penetrates, transmit the torque; slight elasticity in the nylon allows the bearings to give the pinions sufficient working clearance and thus equalise tooth loading.

The gear units are marketed with ratios between 3 and 320 to 1 and in sizes to transmit up to 80 h.p. Although most units are sold for mounting inside a multi-V-belt pulley, special versions are available for chain sprockets, flat belt pulleys and motorised conveyor-belt pulleys. Accessories include elastic torque arms, friction clutch engagements of the brake-shoe type, actuated by hand or solenoid, dog-clutch engagements, torque limiting arms, etc.

EMD 100 for further information

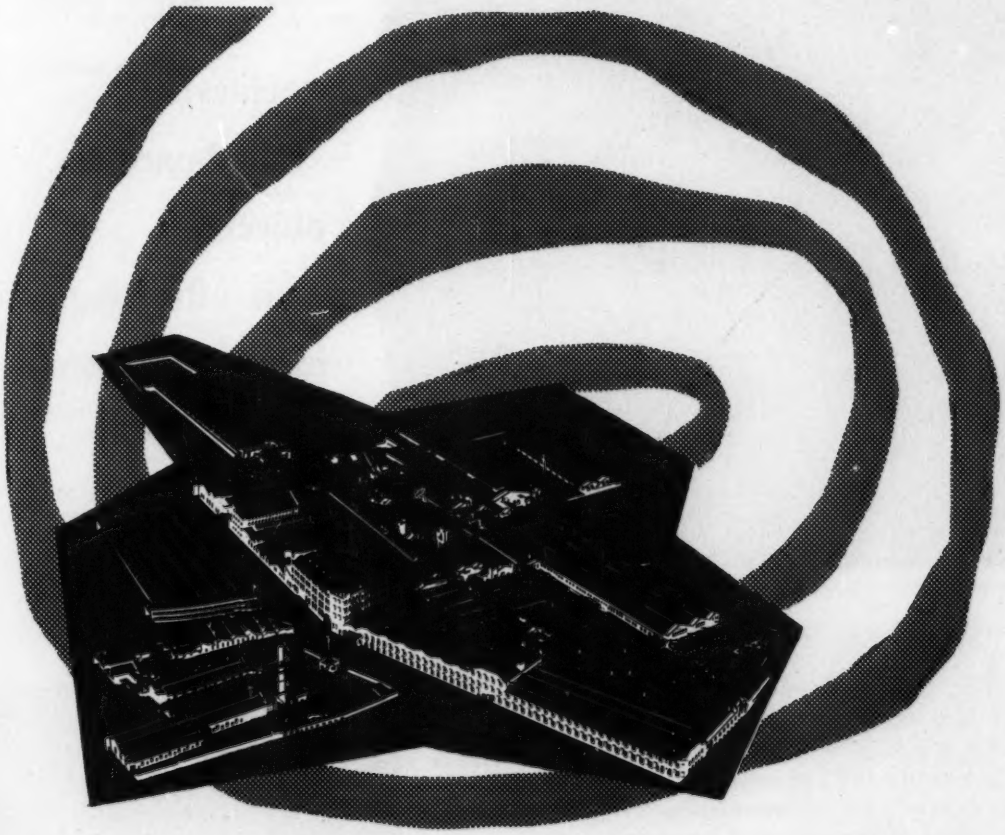
Self-priming Pumps

A new range of self-priming pumps is being introduced by Hill-Barnes (Pumps) Ltd., who have just initiated a production programme in their new works at Markfield, Leicester. The pumps are being made under licence to the design of the Barnes Manufacturing Co., Ohio.

The principal advantage claimed for the design is that the pumps will prime down to 25 ft. suction lift with as little as one-third of the normal water level in the pump body. By virtue of this feature, leakage of water through the discharge connection or suction clack valve whilst the pump is standing idle or being transported will not affect the self-priming characteristic. The pumps are available in sizes from ¾-in. to 6-in. dia. hose connections, with discharges from 1,000 to 90,000 gals./hr. They can be

continued on page 57

design for power



with power transmission equipment by Crofts of Bradford

makers of: *Clutches, Conveyor Drives, Couplings of all types, Double helical gear units, Fabricated steelwork, Geared motors, Hydraulic couplings, Iron, steel and non-ferrous castings, Machine-cut gears of all types, Motorised rollers, Patent Taper-flush-bushes, Plummer blocks, Shaft-mounted gear units, Special machinery drives, Spiral bevel gear units, Turbine gears, V-Rope Drives, Variable speed drives, Worm reduction gears.*

no modern design department should be without a comprehensive set of Crofts Technical Publications Bona fide requests will be dealt with promptly by our Publicity Department at Bradford, or by any of the Branch Offices at: Belfast, Birmingham, Bristol, Cardiff, Dublin, Eastern Counties, Glasgow, Ipswich, Leeds, Liverpool, London, Manchester, Newcastle, Northampton, Nottingham, Sheffield, Stoke-on-Trent

CROFTS (ENGINEERS) LIMITED

POWER TRANSMISSION ENGINEERS

Head Office: Thornbury Bradford 3 Yorkshire

Telephone: 65251 (20 lines) Telegrams: "Crofters Bradford Telex" Telex 51186

"achieves the board's objective of offsetting increasing costs by greater efficiency . . . "

Factory Manager

IT is the ambition of every board of directors to reduce operating costs. Only in that way can an effective contribution towards a reduced cost of living result. The industrial, technical and financial press has been unanimous in its praise of our efforts in offsetting increasing production costs by greater efficiency. The new die-line foundry, for the production of pressure die castings, at our Graiseley Hill Works has been described as " . . . well in advance of American ideas". The economies that have resulted can become an important contribution in lowering your costs of production.

THE WOLVERHAMPTON DIE CASTING CO. LTD.

GRAISELEY HILL WORKS
WOLVERHAMPTON
Telephone: 23831/6

continued from page 54

employed with heads up to 400 ft. Each size will handle solids up to 25 per cent of the flow, with diameters up to one quarter that of the suction connection.

EMD 101 for further information

Anti-abrasion Coil

The Plansel anti-abrasion coil, made by Creators Ltd., is suitable for winding around cable harnesses to protect the cable asemblies from abrasion. This can be done while the harness is *in situ*.

The coil is also suitable for protecting copper pipes and flexible rubber or p.v.c. pipes at points of friction. Made of plastic material, the coil is resistant to acid and will withstand very high pressure before crushing. It is made in continuous lengths of ¼-in., ½-in., 1-in., 2-in. and 2½-in. bore.

EMD 102 for further information

Graphite Flange Lubricating Rods

The Morgan Crucible Co. Ltd. are producing graphite rods for the lubrication of cranes and locomotive wheels where wheel flange and rail wear is caused by excessive friction. The rods, which consist of a soft graphite mixture encased in a harder carbon tube, can be applied to a wheel flange only and, as the lubricant is solid, it cannot creep to the tread. The rods are held in contact with the flange in a simple holder by gravity, by a spring, by air pressure or by a weight-loaded mechanism.

EMD 103 for further information

Hydraulic Power Unit

To meet an increasing demand for a compact source of hydraulic power to operate presses, jacks and similar equipment, Charles S. Madan & Co. Ltd. have designed a new range of com-

pressed-air-operated pumps.

This design, known as the Airhydro power unit, fills the gap between the standard Airhydropump, which is sometimes too large or too expensive for many applications, and the junior Airhydropump, which has a limited output.

The pump works on the principle that the air pressure applied to a large air piston imparts a thrust to a hydraulic ram of smaller area and creates a high hydraulic pressure. The proportion of the air piston area to the hydraulic ram area is the ratio of the pump.

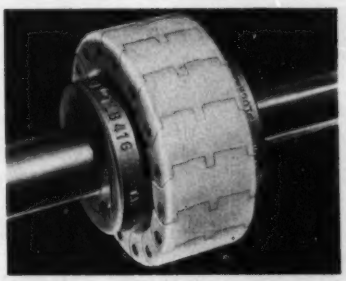
There are nine models covering a hydraulic pressure range from 62 to 22,500 p.s.i. from a normal compressed-air supply of not more than 100 p.s.i. The weights of the complete units vary from 50 to 80 lb. All models are 12 in. high and overall diameters vary from 7½ in. to 12 in., depending on ratio.

An important feature of this type of pump is its ability to maintain a static pressure indefinitely without consuming any air.

EMD 104 for further information

Nylon Coupling

The addition of a new lubrication-free nylon coupling to its line of flexible couplings has been announced by Morse Chain Co., New York. Completely corrosion-resistant, the chain element of the



new coupling is constructed of nylon segments and stainless-steel pins. It can be disassembled or connected at any link without special tools, and fits standard, stock steel roller chain sprockets. Expensive hardened steel sprockets required by conventional steel chain couplings are no longer necessary.

The new coupling needs no protective cover, handles loads from fractional to 40 h.p. and speeds from 500 to 5,000 r.p.m. Complete couplings (¼-in. pitch links and soft steel sprocket) or chain elements are available at a cost of about 20 per cent less than their all-steel counterparts.

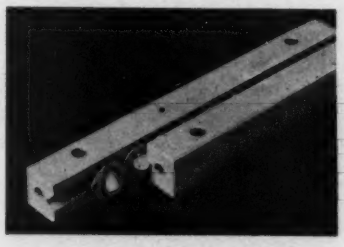
EMD 105 for further information

Linear Bearings

A development which opens a new field of opportunities for designers of machines as well as for other applications such as jigs, tools and various equipment is the range of linear ball and roller bearings supplied by Engineering & Scientific Equipment Ltd.

Linear bearings, with very low coefficient of friction, will last very much longer than the present-day conventional slides because of less damage due to wear, but once these linear bearings are worn out, they can be quickly replaced within hours by another standard set. No special machining is required for fitting these bearings.

The tracks for these linear bearings are made from special alloy steel, carefully machined and treated for stability and great hardness. They are also ground and lapped within a tolerance of 0·00001 in. for each 2-in. length. Between the tracks are fitted high-preci-

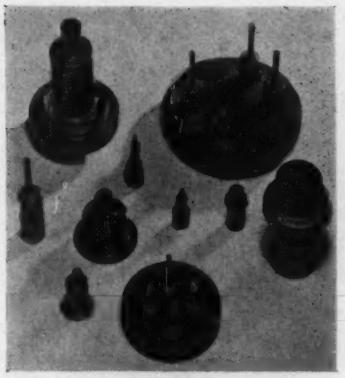


sion balls or rollers. These linear bearings are made in a range of standard types and sizes.

EMD 106 for further information

Ceramic-to-metal Seals

Ferranti ceramic–metal seals have been developed to overcome the limits imposed upon valve performance by the use of conventional glass-to-metal seals. Uses are apparent in other fields, particularly as terminals for vacuum and pressure vessels operating at elevated and sub-normal temperatures. The seals incorporate ceramics of high-alumina content, having high mechanical strength



and good electrical insulation, bonded to nickel alloys to produce strong compression seals.

EMD 107 for further information

Omni-directional Conveyor Roller

A new fitting has recently been developed by Autoset (Productions) Ltd., of Birmingham, in the form of a main load ball supported on a bed of balls which recirculate and provide an endless track for the main load ball. This arrangement provides a load-bearing roller which is omni-directional.

Present production is confined to a horizontal flange-type fitting, having a capacity of one ton and also a screwed peg type of fitting having a capacity of 700 lbs., but other ranges are being developed.

EMD 108 for further information

News of Industry

Mr. J. Bell, chief draughtsman of Distington Engineering Co Ltd., has been elected president of the Cumberland subbranch of the Association of Mining, Electrical and Mechanical Engineers for 1958-59.

Mr. Leonard Summers, F.R.S.A., N.D.D., has been appointed to the research and development division of W. M. Still & Sons Ltd. to concentrate on new automatic vending and catering equipment.

Mr. P. B. Ward, formerly sales manager of Danite Hard Metals Ltd., has been appointed sales manager of Technical Designs Ltd.

Mr. G. Butler, A.M.I.Prod.E., chief designer of the Butler Machine Tool Co. Ltd., has been appointed to the board of directors.

The plastics division of **Metal & Plastic Compacts Ltd.** has now changed its name to the Motoplas Co. Ltd., and the metals division of M.P.C. will be known as Metal & Plastic Components Ltd. Metal & Plastic Compacts was set up by the B.S.A. Co. in 1946 to investigate powder metallurgy and manipulation and moulding in the plastics field.

Titanium Metals Corp. of America has expanded its operations to Europe by collaboration with Deutsche Edelstahlwerke (D.E.W.) of Germany. A new company, Continental Titanium Metals Corporation, will produce and market titanium metal in Europe.

Entrants for the **British Plastics Federation** design award (for articles suitable for moulding or fabricating wholly or mainly from plastics) are reminded that the closing date for entries is September 30. Entries for the annual design competition of **I.C.I.** plastics division (for retail articles moulded from Alkathene) must be in by October 31. The national competition launched by **Freeman Taylor Machines Ltd.** (to find inventions that they can manufacture and market overseas) closes on October 31.

The Birmingham Engineering Centre is to organise, at the request of the F.B.I., a group stand at the British Trade Fair at Lisbon from May 29 to June 14 next year.

The stand will be run on similar lines to that organised at the Brussels Exhibition, with the Engineering Centre arranging construction of the stand, publicity and display.

The Federation of Engineering Design Consultants has announced that it is to initiate soon a limited advertising campaign to publicise the value of design consultants to industrial development.

The **Zinc Development Association** has produced a new 20-minute film, entitled *No Rust Here*. This describes the hot-dip galvanising process and illustrates its many applications in building, mining, railways and many other aspects of engineering. British and foreign examples of its use are given, as well as a description of the galvanising process.

The ensecote department of **Newton Chambers & Co. Ltd.** near Sheffield has been extended and modernised to increase facilities for protective plastics linings for industrial plant. A new feature of the plant is the pressurised spraying chamber in which the air is filtered to prevent dust affecting coated surfaces during treatment.

The coachbuilding firm of **Jas. Whitson & Co.** has turned its production over entirely to polyester-glass fibre work. The company is now using these mouldings exclusively for motor bodies as well as for street luminaires and fittings and chemical cabinets, produced from Cellobond resins supplied by **British Resin Products Ltd.,** and glass fibre sheeting.

Managing director of Whitsons, Mr. A. E. Whittit, says his company is making progress in mechanising the hand lay-up process and in chroming polyester-glass.

London sales office of **Brook Motors Ltd.,** has moved to larger premises at 1-2 Finsbury Square, E.C.2. New Telephone number: METropolitan 9401-7.

A British engineering display is to form a section of the **Canadian National Industrial Production Show** in Toronto from May 4 to 8 next year. It will be organised jointly by the Board of Trade and the Birmingham Engineering Centre.

To celebrate the diamond jubilee of the **Villiers Engineering Co. Ltd.,** a special exhibition of products using Villiers and J.A.P. engines is to be held at the Horticultural New Hall, Westminster, on January 7 to 9, 1959.

The research department of **Samuel Fox & Co. Ltd.** has changed its title to metallurgical department to reflect more accurately the nature of its work.

The executive offices of **Kelvin & Hughes Ltd.** have been transferred to Empire Way, Wembley, Middx. (Tel.: Wembley 8888.)

A laboratory extension costing £15,000 is in course of construction for the **English Metal Powder Co.** at West Drayton. The laboratory will be concerned with research for users of the company's products and will contain the latest equipment for testing aluminium stove enamels and other resin-based aluminium paints.

Finishing off chloride equipment cabinets in polyester-glass fibre for Wallace & Tiernan Ltd. at the works of Jas. Whitson & Co. Ltd. (*Photo: British Resin Products Ltd.*)

Designer's Diary

METALS

Sept. 23-26. *Nickel and Nickel Alloys Exhib.* Royal Station Hotel, Newcastle. (Henry Wiggin & Co. Ltd.) Also at Metropole, Leeds, Oct. 14-17; and at Grand Central Hotel, Belfast, Oct. 28-31.

Sept. 29-Oct. 3. *Int. Metal Spraying Conference.* College of Technology, Gosta Green, Birmingham. (Assoc. of Metal Sprayers.)

Oct. 28. Symposium on Aluminium Pressure Vessels. London. (Inst. of Mechanical Engineers.)

PLASTICS

Sept. 23, 24. *Industrial Uses of Nylon Exhib.* Commerce Assembly Room, Birmingham. (I.C.I. Ltd.) Also at Angel Hotel, Cardiff, Oct. 14 and 15; and Grand Hotel, Charing Cross, Glasgow, Oct. 29 and 30.

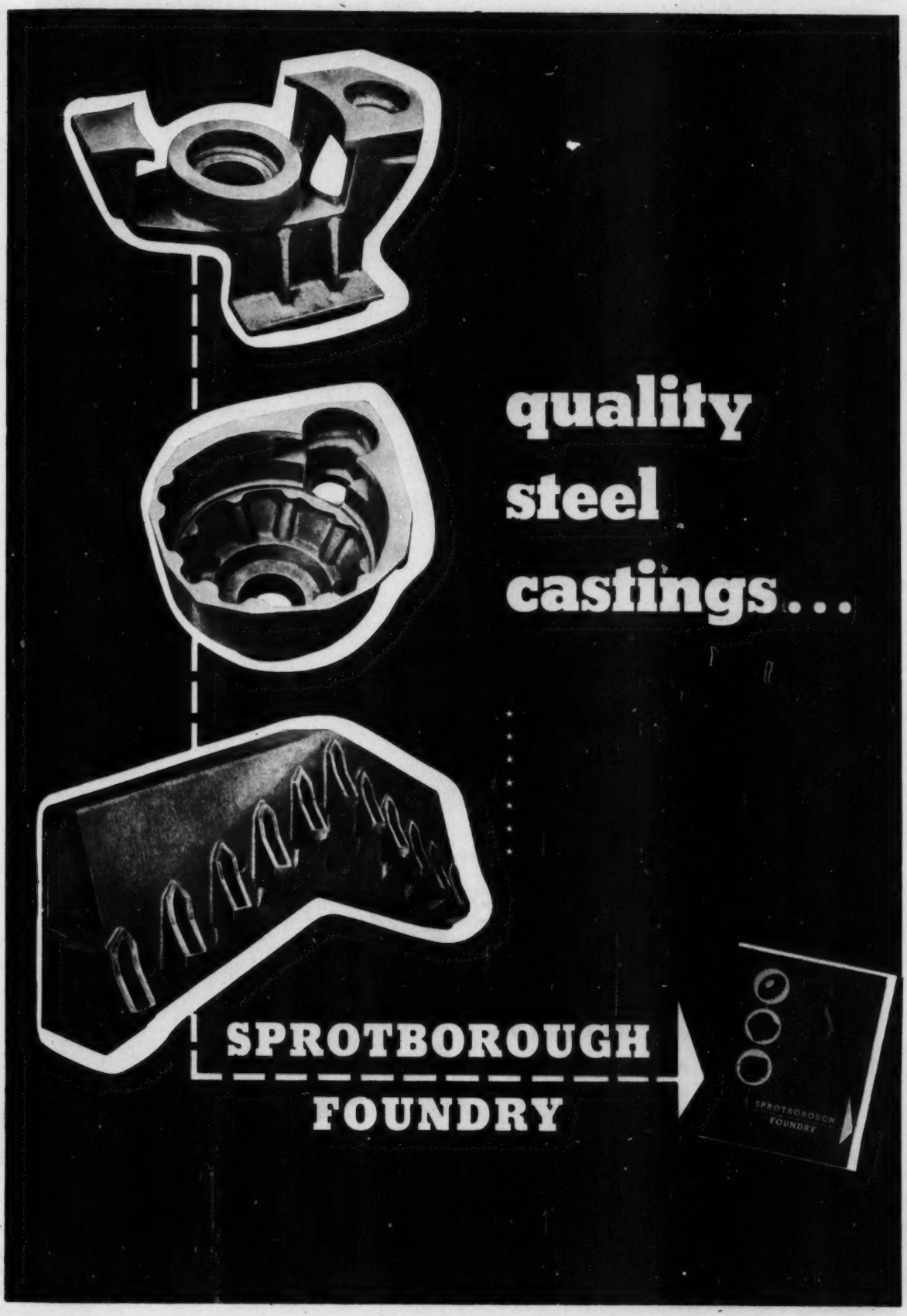
Oct. 6-Nov. 24. *Series of lectures and films on plastics* for non-technical members of industry. City of London College. Mondays at 6.15 p.m.

Oct. 21-24. *Reinforced Plastics Technical Conference.* Brighton. (British Plastics Federation.)

GENERAL

Sept. 23-25. *Int. Conference on Gearing.* London. (Inst. of Mechanical Engineers.)

Oct. 21-23. *Engineering Industries Assoc. Display.* New Horticultural Hall, London.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EMD 36 for further information

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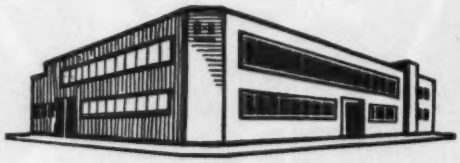
EMD 37 for further information

THE MIDLANDS LEADING STOCKISTS OF

ALUMINIUM

and its alloys



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mill quality at mill prices.

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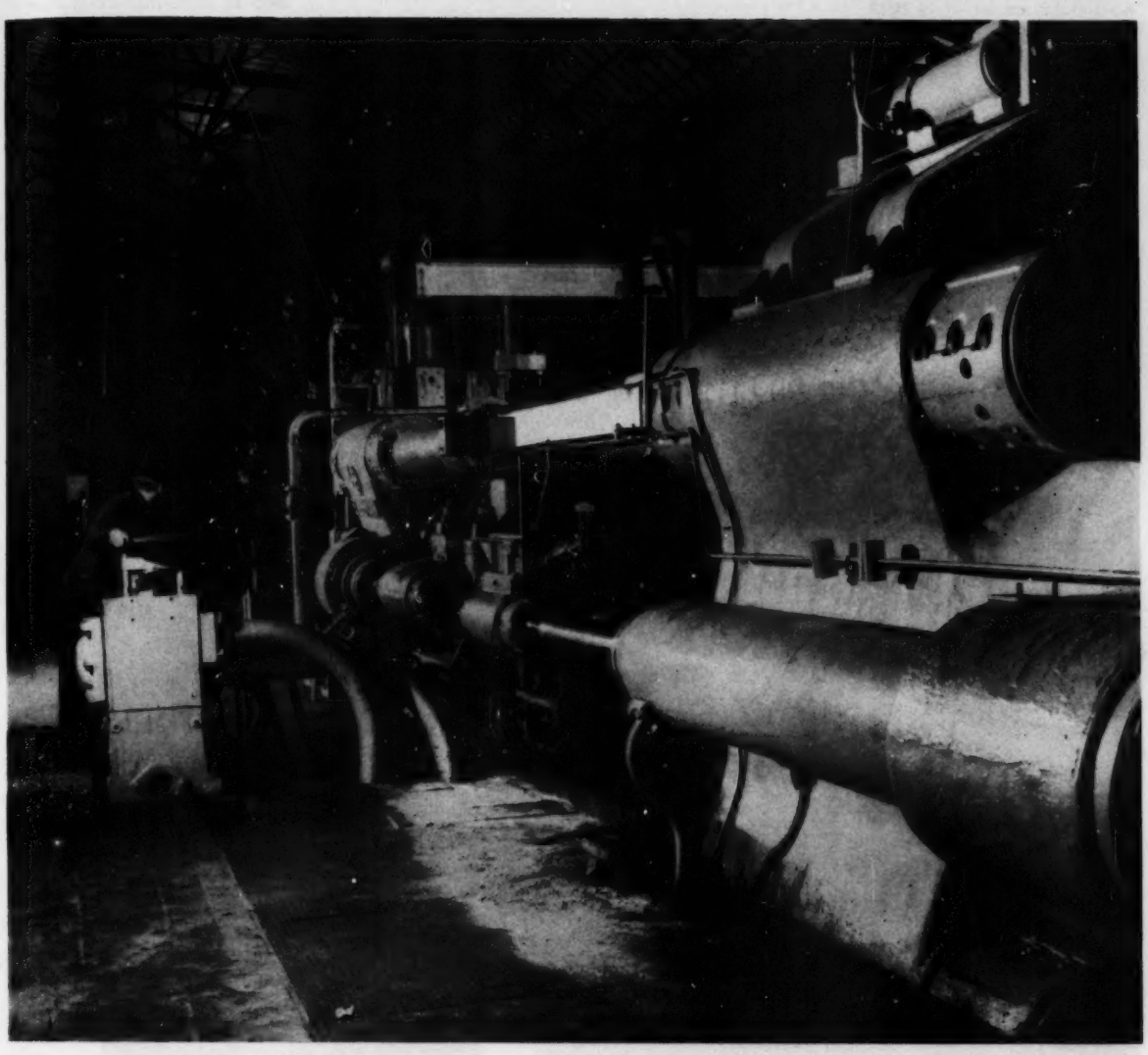

This large extrusion press is installed at the Latchford Locks Works; here aluminium alloy extrusions are produced in sizes up to 13½" circum-circle.

Sections are designed and produced for use in the construction of welded and riveted assemblies for the road transport, shipbuilding, building and structural and general engineering industries. British Aluminium also manufacture a wide range of alloys in the form of plate, sheet and coiled strip.

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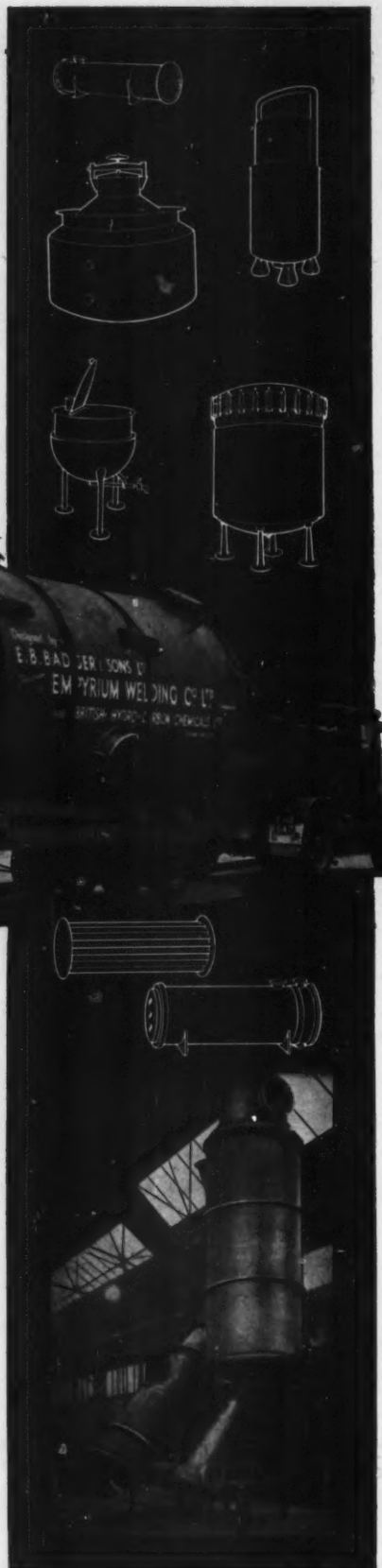
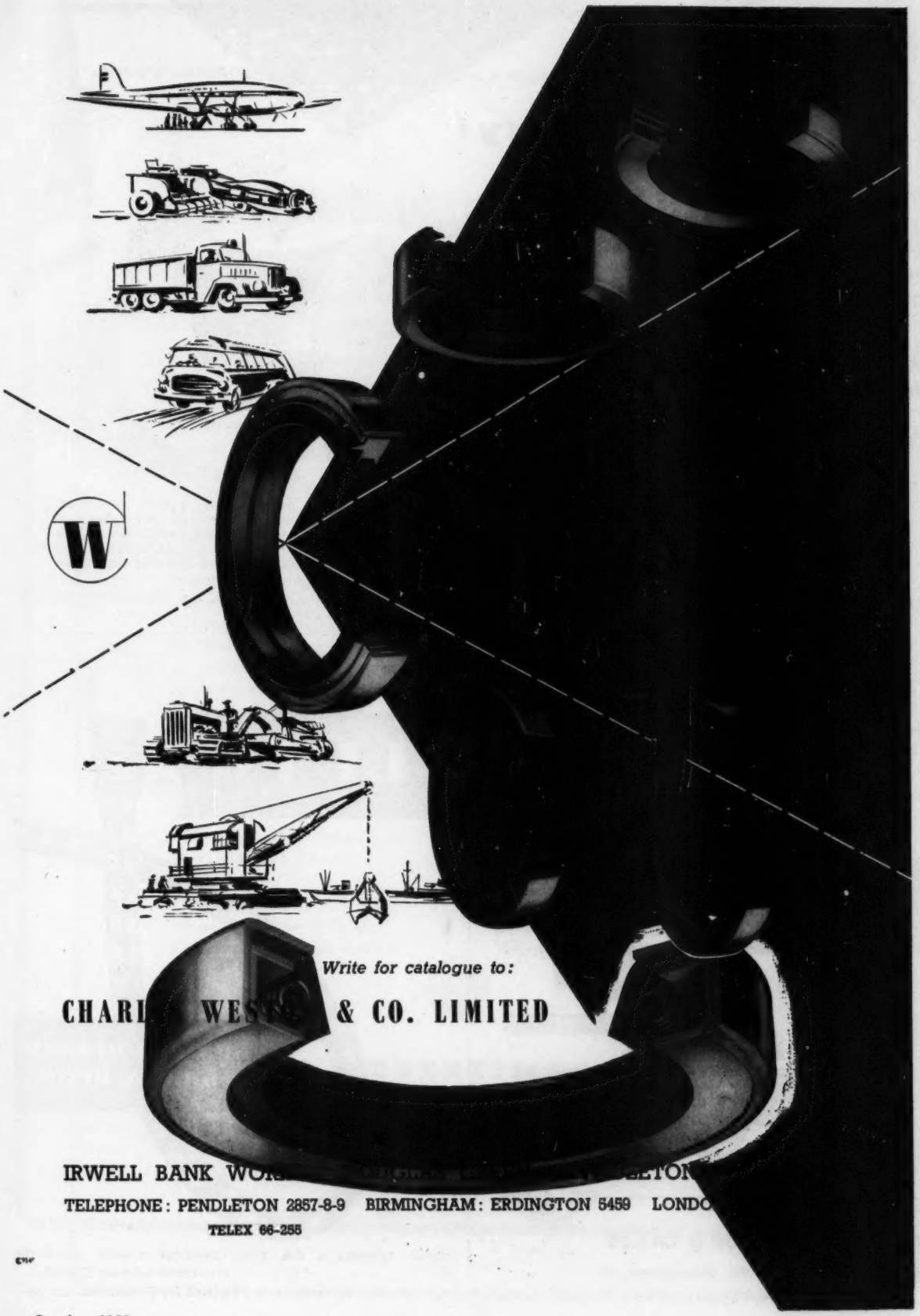
pioneers in welding practice since 1917



JW. Ad 4079



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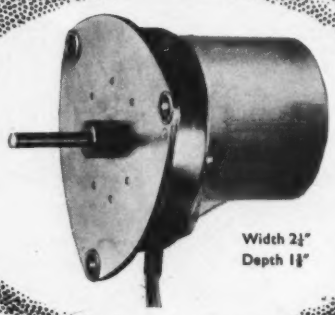

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This choice should spring from a natural aptitude for understanding the approach to industrial markets and the belief that much can be done to raise industrial advertising to new levels of efficiency.

Such an agency will employ, as we do, creative writers with scientific and engineering training: it will have a marked ability to grip the interest of the buyer in industry: it will have a most valuable accumulation of experience on which the industrial advertiser can draw.

We describe our service more fully and show recent examples of our work in an interesting brochure called 'Advertising to Industry'. You can see from the list below some of the 130 accounts we handle.

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Access Equipment Ltd
Avica Equipment Ltd
BX Plastics Ltd
British Hydrocarbon Chemicals Ltd
The Cape Asbestos Co Ltd
Crawford Collets Ltd
The Distillers Company Ltd (*part*)
Alexander Duckham & Co Ltd
English Abrasives Corporation Ltd
Expanded Rubber Co Ltd
Flight Refuelling Ltd.
John Harris Tools Ltd
International Meehanite Metal Co Ltd
E & E Kaye Ltd
Keith Blackman Ltd
George Kent Ltd
Londex Ltd
Mulhead Engineering Co Ltd
Senior Economisers Ltd
Siemens Edison Swan Ltd (*Part*)
Venesta Ltd

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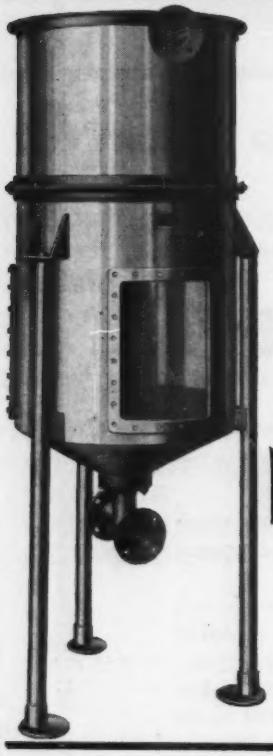

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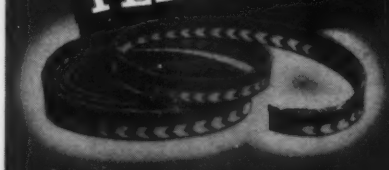
Stop draughts WITH FLEXIBLE BRUSH WELT



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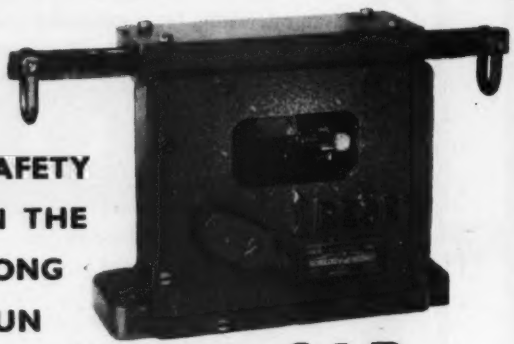

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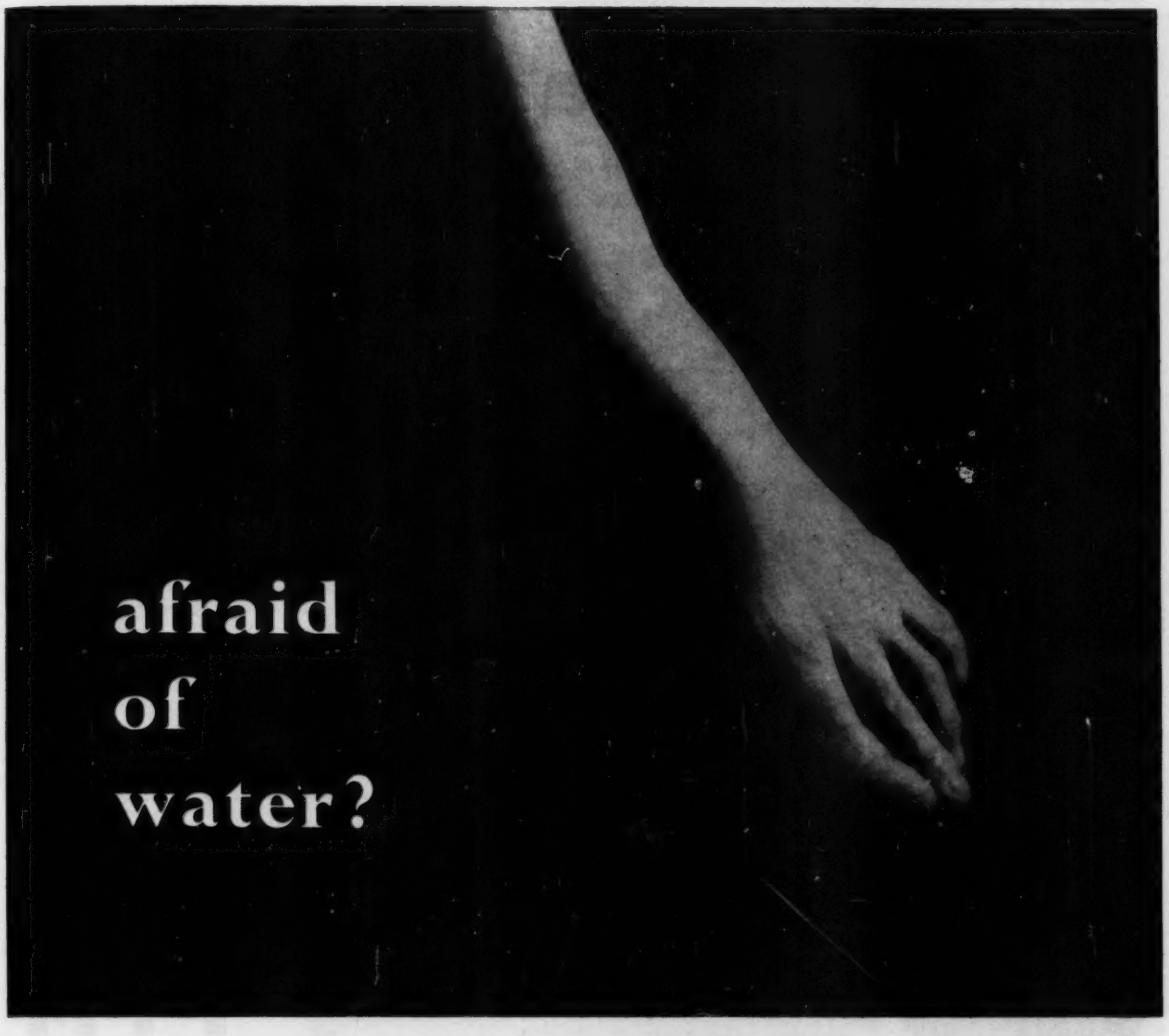

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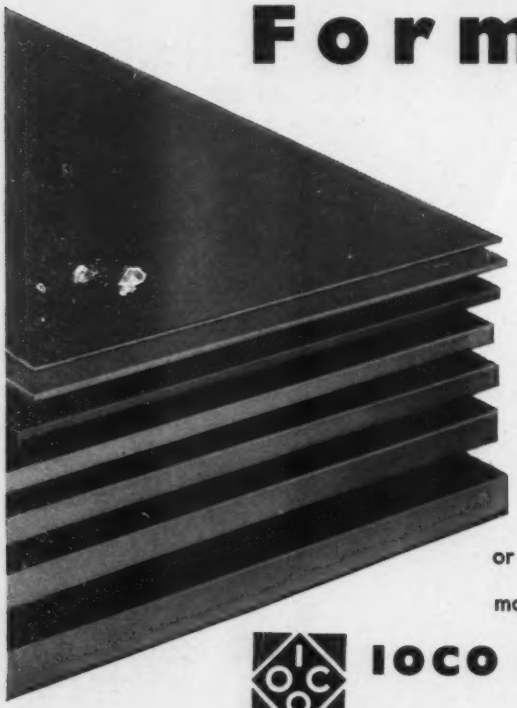

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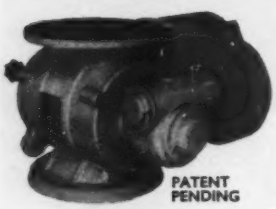

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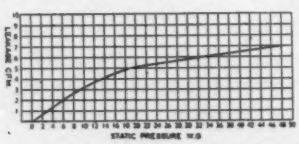

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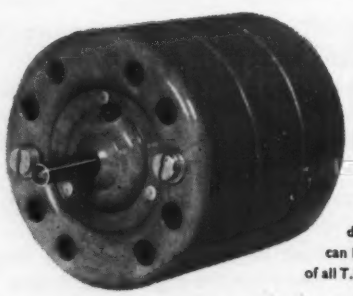

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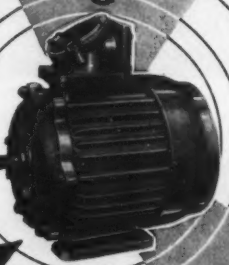

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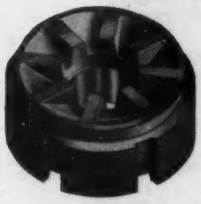

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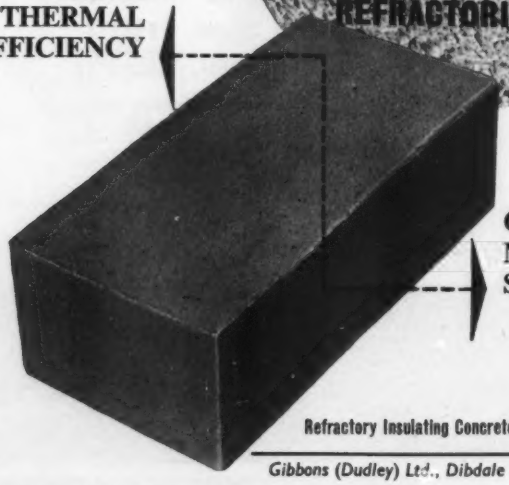

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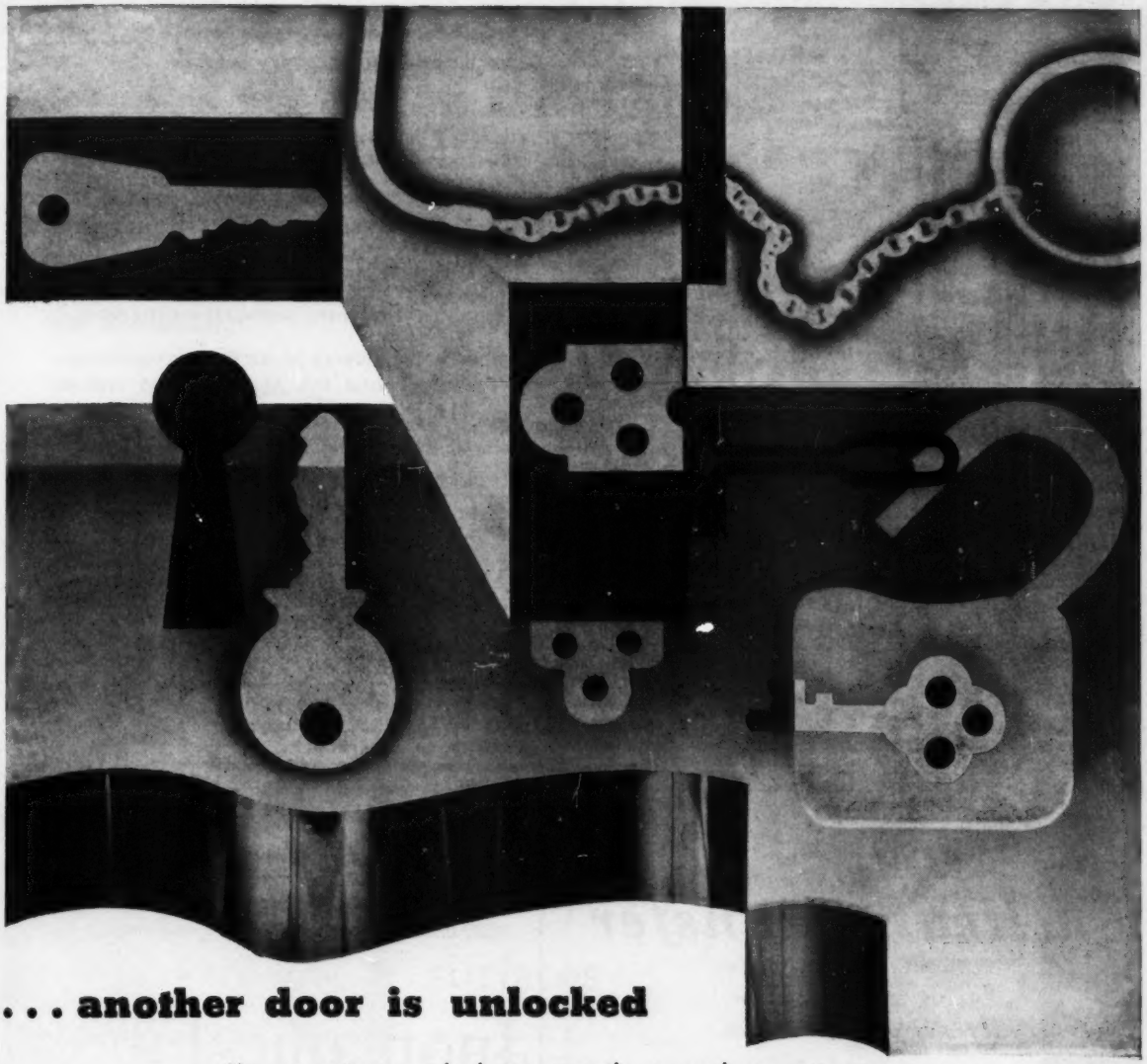

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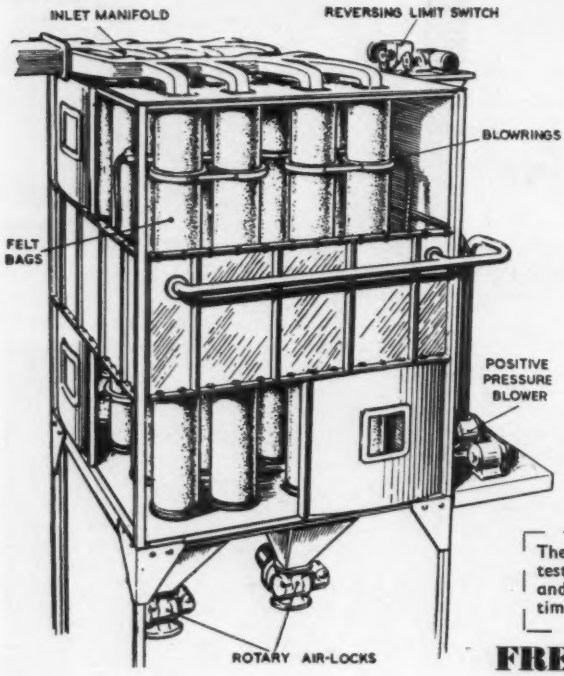

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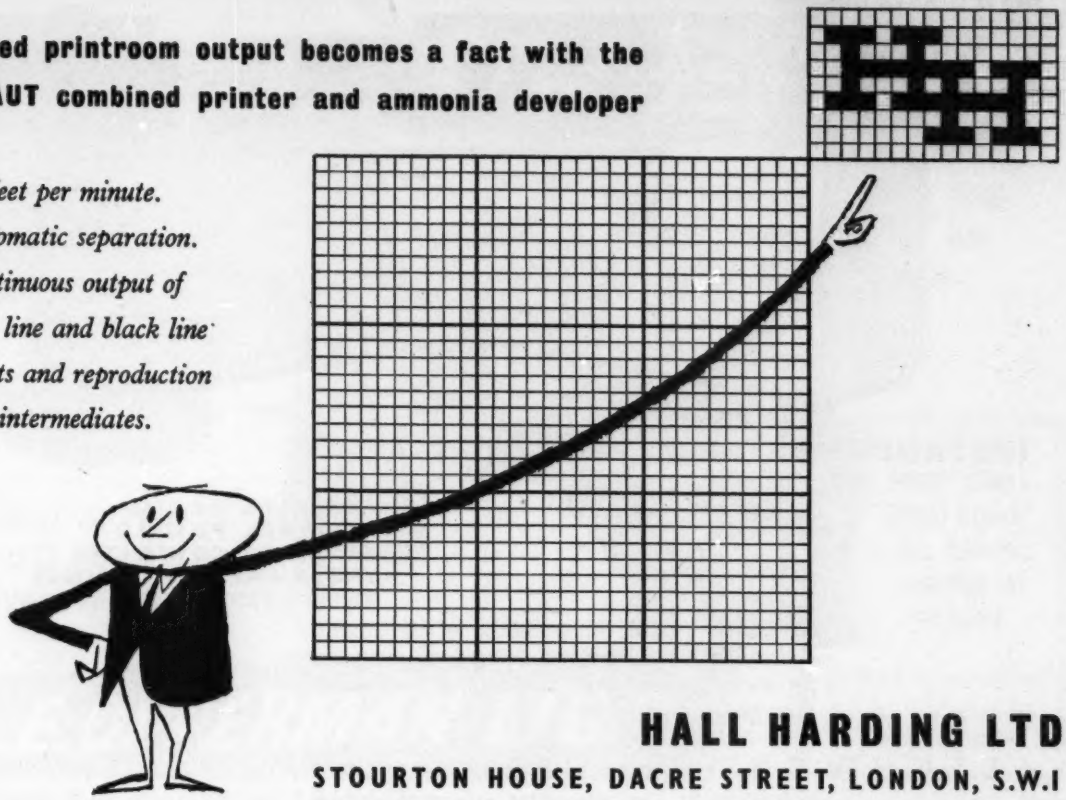

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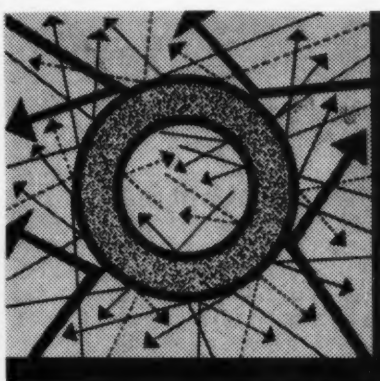

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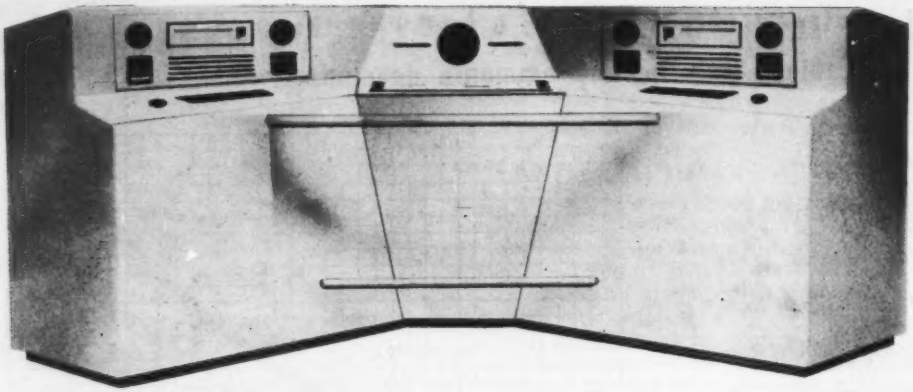

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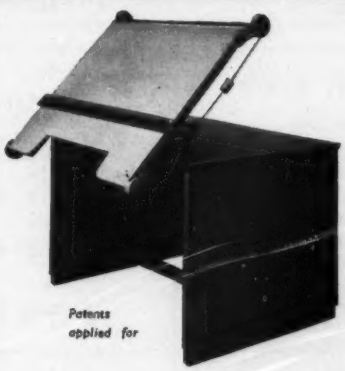

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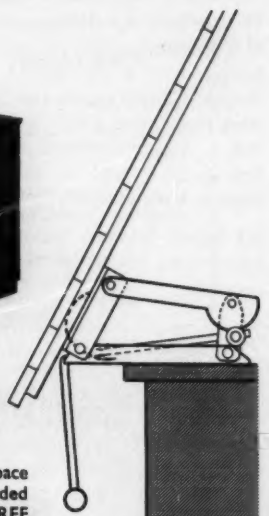

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